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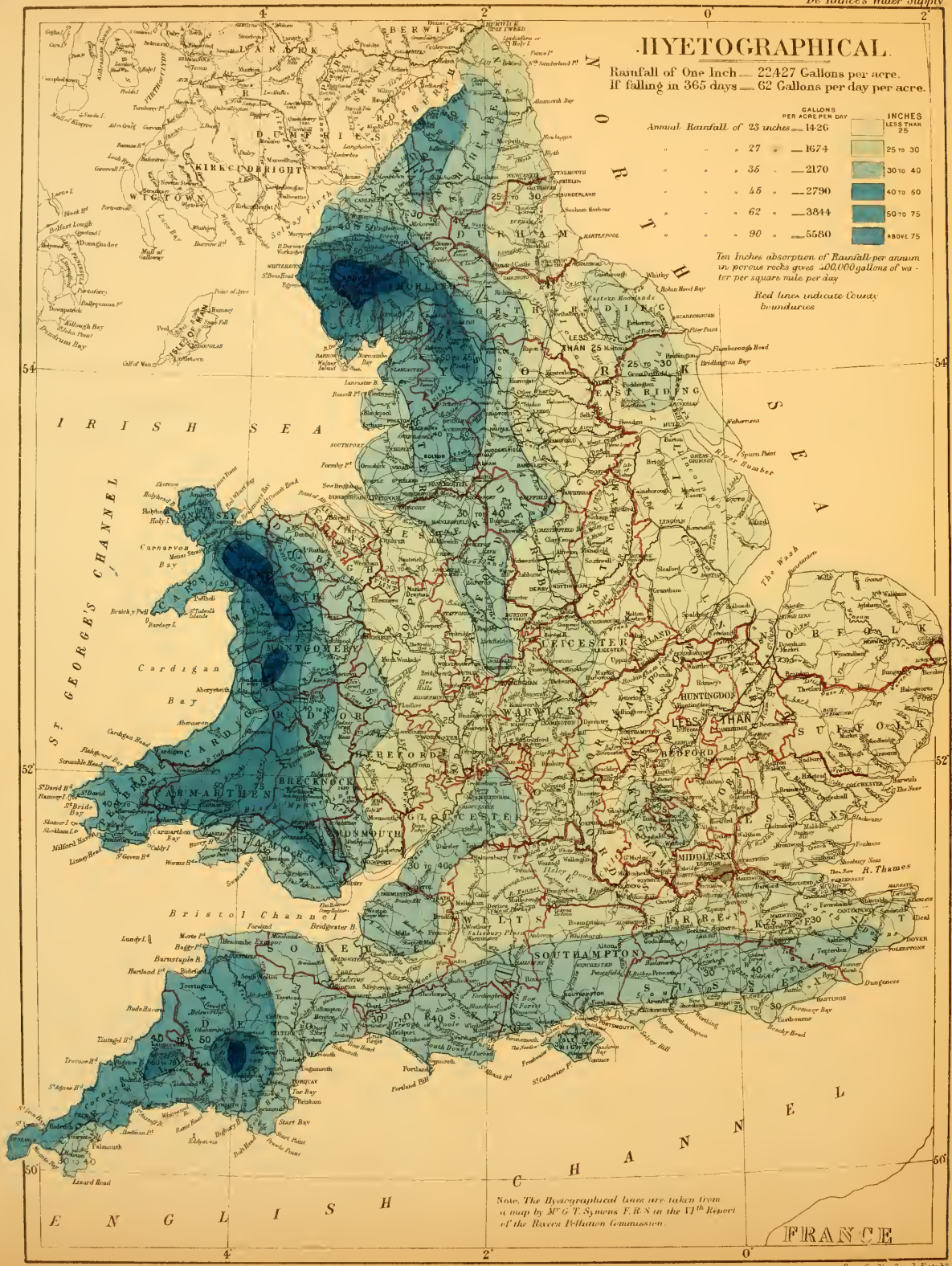
THE WATER SUPPLY

OF

ENGLAND AND WALES.



London; Edward Stanford, 55, Charing Cross, S.W.

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THE WATER SUPPLY

OF

ENGLAND AND WALES;

ITS GEOLOGY, UNDERGROUND CIRCULATION, SURFACE DISTRIBUTION, AND STATISTICS.

BY

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LONDON:
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PREFACE.

My attention was forcibly drawn in 1873 to the direct relation of the varying character of water to the geological formations through, or over, which it flows, when I was assisting in classifying, according to the geological position of their source, the analyses of potable waters made by the Royal Rivers Pollution Commission, published in their Sixth Report. In the following year the British Association appointed a Committee of Inquiry into the Underground Circulation of Water, with Professor Hull, F.R.S., as Chairman, and myself as Secretary; and from that time I have been continually investigating this part of the subject.

In 1878, the Council of the Society of Arts, at the request of their President, His Royal Highness the Prince of Wales, convened a Congress to consider the question of Water Supply. To this Congress, and the succeeding Congress of 1879, I was invited by the Council to contribute; and the Papers I then read, combined with the "Lectures on Water Supply" which I gave to the Wigan Mining School in 1876, form the basis of the present work.

I have endeavoured to show the character and quantity of the water at present supplied to every town and Urban Sanitary Authority in England and Wales; and, by describing the area of the principal geological formations, with the amount of rainfall (determined by Mr. G. J. Symons) in

each of the river-basins delineated in the Catchment Basin Map of the Ordnance Survey, to afford data for estimating the volume of water *available*, and, through the population figures of the 1881 census, the quantity of water *required*, for human consumption, in each group of river-basins.

I am indebted to many Geologists and others who have kindly aided in the work, but I would specially acknowledge the valuable assistance, in revising some of the proof-sheets, given by Professor Prestwich, F.R.S., of Oxford, and Dr. John Evans, F.R.S.; and the important information I have received at various times from Messrs. Charles Hawksley, Henry J. Marten, Baldwin Latham, S. C. Homersham, and J. N. Shoolbred, Members of the Institute of Civil Engineers; from Professor Lebour, of the Newcastle College of Physical Science, Dr. Campbell Brown, of the Infirmary, Liverpool, and Mr. G. J. Symons, F.R.S.; from Dr. Buchanan, and Dr. Thorne Thorne, of the Medical Department of the Local Government Board; and from my colleagues, Professor Hull, LL.D., F.R.S., and Messrs. Whitaker and Topley, of the Geological Survey. Mr. T. W. Newton, of the Museum of Practical Geology Library, has given valuable help in seeing the work through the press.

C. E. R.

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PLAN OF THE WORK.

Rivers flowing directly into the Sea are printed in Italic Capitals, tributary streams in small Italics.

The towns and tributaries on the left bank of a stream are in all cases described first, proceeding from the outfall of the river to its source, then along its right bank from its source to its outfall. The left bank of a river is that on the left hand when standing with the back towards its source, facing the direction in which it is flowing.

Urban Sanitary Authorities are printed in small Roman Capitals, except where a group of Authorities derive their water supply from one township, in which case it is placed first, and alone printed in Capitals.

Geological formations mentioned for the first time, and influencing the water supply of a district, are printed in Italics.

The Statistics of the Urban Sanitary Authorities are taken from a return made by the Local Government Board in 1879; the Census figures from the Preliminary Report of the Census 1881, published in July.

ERRATA.

Page 51, lines 2 and 7 from top, *for* ALYN *read* ALN.
„ 55, line 2 from bottom, *for* WHITBY *read* WHITLEY.
„ 75, „ 7 „ top „ Kirklington-cum-Repsland *read* Kirklington-cum-Upsland.
„ 81, „ 10 „ „ „ 2903 „ 3685.
„ 93, „ 6 „ „ „ PICKHILL *read* TICKHILL.
„ „ „ 6 „ „ „ 1915 (?) „ 1820.
„ 122, „ 12 „ bottom „ Martin „ Marten.
„ 195, „ 8 „ top „ Bunaby „ Barnaby.
„ „ „ 10 „ „ „ lentem „ lentum.
„ 216, „ 4 „ „ „ square miles *read* miles.
„ 232, „ 2 „ „ „ ABOVE *read* ABOVE AND BELOW.
„ 248, „ 3 „ „ „ CXXVI. *read* CXXXVI.
„ 263, „ 7 „ „ „ 337 „ 373.
„ „ „ 8 „ „ „ 265 „ 301.
„ 412, „ 1 „ „ „ DYSMI (XXVIII.) *read* DYSNNI (LXXVIII.).
„ 415, „ 10 „ „ „ LXIV. „ LXIII.
„ 433, „ 11 „ „ „ hill. „ hill,
„ 443, „ 1 „ „ „ CI. „ XLVIII.

THE WATER SUPPLY

OF

ENGLAND AND WALES.

CHAPTER I.

RAINFALL AND PERCOLATION OF RAINFALL.

According to Mr. Symons' map, accompanying the Sixth Report of the Rivers Pollution Commission, the rainfall of England exceeds 25 inches per annum throughout the entire area lying west of a line ranging from Shields to Reading, whilst west of a line trending from Shields to Start Point the rainfall around the Lower Palæozoic rocks, forming the elevated tracts of the English Lake District, of Wales, and of Dartmoor, amounts to more than 75 inches per annum. With so large an area, receiving so abundant a rainfall, the existing absence of an efficient water-supply, not only for our larger cities, but for our rural population, becomes a matter of surprise, and an inquiry into the causes, which so often leave the inhabitants of this country, like Coleridge's "Ancient Mariner," with "water, water everywhere, nor any drop to drink," a subject of considerable importance.

The lakes of Cumberland and Westmoreland all lie in true rock-basins, excavated beneath the ordinary valley gradient by glacier action. Thirlmere is one of these natural basins, but the barrier which formerly enclosed the lake has been partially cut through, so that the original level of the lake is lessened. The proposed project for utilizing the lake for Manchester water-supply involves the

restoring of this barrier by an artificial embankment, so as to raise the water-level, and give a greater storage capacity.

The available rainfall is calculated on the average fall of a district over a long period of years, but the amount varies during the dry years of that period, as stated by Mr. Bateman in his evidence before the Royal Commission on Water Supply, "according to the declivity and geological character of the country, and its cultivation, and the amount of vegetation—the quantity which is taken up by vegetation, or is evaporated or lost in rivers, varying from about 9 inches to 16 inches, the smallest quantity being of course that where the rocks are hardest, and the declivities are the greatest, so that the water comes down in floods."

In the Loch Katrine district, and in the Welsh hills around the sources of the *SEVERN*, with an actual average rainfall of 75 inches, Mr. Bateman takes 60 inches as the available average, of which not less than 12 would be lost by evaporation, &c., being a mean between 9 inches and 16, leaving a net available produce of 48 inches. In impermeable districts consisting of the older Palæozoic rocks, rising to great elevations, the dry weather flow of the streams, due to springs only, amounts, according to Mr. Bateman, to one-fourth of a cubic foot to three-fourths of a foot per second from each 1000 acres of area drained, giving an average of half a foot per second for a dry season, while the volume carried down by floods ranges from 200 to 500 cubic feet per second, or 500 to 1000 times the dry weather flow. Reservoirs impounding these floods are able to increase the useful volume of the stream by returning one-third to one-fourth of them as compensation.

The amount of rainfall in a mountain district steadily increases in direct proportion with the elevation up to a height of 2000 feet, which falls chiefly on the side nearest the direction of the prevalent rain wind; thus the wet winds of the Lake District are the dry of Northumberland. When, however, the hills rising to 3000 feet are breached by valleys of lower elevations than 2000, the rain clouds are

carried through, and their contents precipitated on the lee slope of the hills, as at Wastdale Head and Beddgelert.

Similarly, in the Pennine chain, Mr. Bateman gives the following averages of the 10 years 1856–1865, and ranging along a line from south-west to north-east:—at Standish, 300 feet above Ordnance Datum* (Wigan Waterworks), 41·14; at Rivington (Liverpool Waterworks), mean of several gauges at different heights on the westerly side of the hill about 700 feet above Ordnance Datum, 45·22; at Belmont (Bolton Waterworks), in the first deep valley east of the first range of hills, 800 feet above Ordnance Datum, 52·72; while still further east, in Pick-up Bank (Blackburn Waterworks), 650 feet above the sea, it is only 44·08.

Mr. Bateman gives further gaugings across the Pennine chain, taken along the line of the Rochdale Canal, which show to a marked degree the abstraction of moisture caused by the intervention of a range of hills. Average of the three years 1846 to 1848, at Rochdale 34·25; at White Holmes, Blackstone Edge, 1200 feet above the sea, 52·55 inches; at the Toll Bar, on Blackstone Edge, 1000 feet, 53·16 inches; at Black House, Blackstone Edge, 1000 feet, 51·80 inches; and at Sowerby Bridge, on the other side of the hills, at an elevation of 300 feet, it is 29·85 inches.

Mr. Bateman also gives gaugings along a west and east line from Manchester, during the 9 years 1859 to 1867. The average of the latter place is 37·76 inches; at Rhodes Wood Reservoir, 500 feet above Ordnance Datum, it is 45·94; at Woodhead Reservoir, 800 feet above Ordnance Datum, 51·01 inches; at Woodhead Station (Manchester, Sheffield and Lincolnshire Railway), 939 feet above Ordnance Datum, 53·88 inches; Penistone, 717 feet, it is 31·11; at Sheffield

* The Ordnance Datum plane is the mean half-tide level at Liverpool, which is 4·75 feet above a mark on the Old Dock Sill, now transferred to St. George's Dock, and 10·75 feet above the Mersey Datum line. The "contours," or lines of equal level, on the six-inch scale maps of the Ordnance Survey, and on their new one-inch scale maps, represent 100-feet levels above this datum, throughout the whole of Britain.

Station it is 27·83 inches; the last three being in the valley of the *DON*.

In districts like the Millstone Grits and Yoredale Beds of the area drained by the existing Manchester Waterworks, though large quantities of water are absorbed by the porous sandstone, and the water supported by the beds of intervening impermeable shale, the rainfall received by the reservoirs has been found to be no less than 38 inches out of a total fall of 45¾ inches, the average of dry years. This small loss, due to absorption, is owing to the fact, that the springs discharging the percolated waters are all within the same hydrographic basin.

Of the chain of reservoirs supplying Manchester, extending over six miles of country, the upper one has an embankment 90 feet in depth, the second 100 feet, the third 80 feet, and the lower two 56 feet, constructed with a puddle-trench in the centre, with slopes of clay overlaid by shale and stone; slopes 3 to 1 on the inside, and 2 to 1 on the out, and pitched inside.

One of the earliest embankments made in Lancashire—at the Turton and Entwistle Reservoirs—is 108 feet high. The service reservoirs of the Manchester Waterworks are 15 feet to 20 feet deep; at less than 15 feet depth, it has been found that vegetation takes place upon the surface of uncovered water, the decomposition of the vegetation affording food for animalculæ, and their consequent abundance.

When large quantities of water are abstracted from streams used for manufacturing purposes, compensation in bulk is invariably given—the working volume of the stream is not diminished, and the working power of the country suffers no loss, but, on the contrary, through the impounding of flood-water the working volume of the stream is increased.

In a few cases, however, legislation has allowed the total abstraction of the water of a river, not then employed for manufacturing purposes, and has thus prevented the stream from ever being utilized.

Perhaps the greatest disadvantage of the system of supply

from surface waters is the great size the reservoirs have to be constructed, to enable them to hold a sufficient volume to provide for the longest droughts, or succession of droughts, known to occur in the district, which in dry areas like Newcastle require provision for 240 days, and in comparatively wet ones like Manchester not less than 120. The large size of these works covering extensive areas of land, generally of good meadow ground occupying the bottoms of a valley, and of a character well suited to provide food-stuff for cattle, is of great importance in a country containing so small an area as England, and consequently obliged to import a large portion of its food supplies.

When natural lakes are used as reservoirs, presenting surfaces already covered with water and incapable of being drained, this objection is of course removed, as in the case of Loch Katrine, which, with an area of 3000 acres, possesses a capacity of 910,000,000 cubic feet.

The great value and agricultural character of the land, consisting of the newer Palæozoic, Secondary and Tertiary rocks, make an inquiry into the amount of water they are capable of yielding when penetrated by deep wells, which do not necessitate large expanses of reservoir space, a matter of considerable interest. Classified according to their water-yielding characters, they may be described as impermeable, pervious, and supra-pervious, the latter consisting of impermeable strata resting on a pervious rock, as the London Clay upon the Chalk, or Boulder Clay upon the New Red Sandstone. The area and thickness of these deposits are described hereafter in each river-basin.

Mr. John Taylor, in his report to the Duke of Richmond's Royal Rivers Commission, states his opinion that none of the great gravitation works have fulfilled the anticipated results. "There is not yet sufficient experience of the variation of rainfall to arrive at any fixed data for guidance as to the probable minimum quantities in cycles of years; for instance, taking the recorded rain at Greenwich from 1817 to 1867, there is only one example of five successive years which

were all below the average fall, viz.: 1854 to 1858 inclusive, in which only 100 inches of rain fell. The average fall of the fifty-one years being 25½ inches, there was actually a deficiency of 26 inches of rain in these five years, or one whole year's rain. This having occurred only once in fifty-one years proves that much longer experience is required to know the various fluctuations that may occur."

Sufficient experience of the possible variation of rainfall is wanting before the absolute minimum rainfall of any district can be fixed, and especially as to what portion of it is available for gravitation waterworks. When they are mainly dependent on springs, the winter rain is of the most importance, and even though the year's fall may be above the average, if the winter is dry, the springs will fall off, especially when two or three *dry winters* succeed each other. Also, the quantity of water available may be much less in one year than in past years, though the actual fall may have been the same. Thus at Liverpool, the late Corporation engineer reports, "in 1862 the rainfall was 48·51 inches, the ratio of impounded water to the rainfall was 82·63 per cent. In 1865, when the rainfall was 34·8 inches, the proportion of available water flowing off was only 67·12 per cent.; so that, apart from the deficient rainfall, that which did fall yielded less by 15·51 per cent. than the rainfall of 1862."

At Newcastle 2 to 3 inches above the average, or 26 or 27 inches, yields 60 per cent. of the fall, while in 1850, when only 17·68 feet, its yield was only 6¼ inches, or 35 per cent. of the fall.

Mr. Taylor states "that, basing calculations on *average* falls of rains is erroneous; the minimum quantities only should be depended upon." Complete security against want of water in exceptionally dry years could only be attained by storing all the flood-waters of two or three successive winters; or, in other words, providing storage for 300 or 400 days' supply to the district. The axiom in mechanics, that the strength of a beam is the strength *only* of its weakest

point, applies also to gravitation waterworks, their real strength or power of supply being only the *minimum quantity* they may be *reduced to*. To be absolutely safe for all periods, it would appear that they ought to be made capable of supplying, in years of average rainfall, twice the quantity of water required, in order to be equal to the deficiency of a minimum year.

As regards discharge from reservoirs, Mr. Hassard states* there is great economy in using large pipes, three lines of 8-feet pipes with a fall of 1 foot 8 inches per mile will discharge as much as ten 4-feet pipes with a fall of 5 feet to the mile. The same velocity may be obtained by the water in passing through a large pipe with a small fall as that in its passing through a small pipe with a large fall, at a cost of 40,000*l.* per mile cheaper in the one case than the other. "The velocity of water in any aqueduct depends upon two conditions: first of all, upon the ratio which the sectional area of the fluid bears to the wetted perimeter or surface with which it is in contact; and secondly, upon the fall. The ratio of the section to the wetted perimeter or frictional surface is technically called the 'hydraulic mean depth,' and that is very much greater in large aqueducts than it is in small ones. A rectangular section of a conduit 12 feet deep and 12 feet wide has a sectional area of 144 square feet. The wetted perimeter is 36 feet, and 144 divided by 36 will give the quantity of 4, which is the hydraulic mean depth. Taking, for example, a small conduit 3 feet square, the sectional area is 9, which, divided into 9, is 1; therefore, in one case the hydraulic mean depth is 4, in the other 1, and that in the larger conduit water would attain the same velocity with a fall of 1 foot per mile as it would in the smaller one with a fall of 4 feet per mile."

Mr. Robert Rawlinson, C.B., officially examined the reservoirs of Lancashire and Yorkshire for the Home Office, after the bursting of the Dale Dyke Embankment, and in his evidence before the Royal Rivers Commission speaks of the

* 'Report, Royal Rivers Commission,' p. 51

great importance of ascertaining the geological conditions before constructing a reservoir embankment, and to the impossibility of making cheap banks, and states that every foot as it rises should be watched; for, as the Hindoos say with regard to an arch, that "it never sleeps," so with water under pressure, it never sleeps, but is everlastingly searching out the weakest point in the reservoir. Thus, at the Dublin reservoir, with good banks, a leak sprung through the culvert being made with hewn granite "ashlar." Beds and joints of masonry are its weakest portion, especially when there is the slightest liability to motion, and outlet culverts should always be constructed of brick or rubble put together with one-third mortar. Mr. Hartley began dock-making and river-walls with ashlar, and gave it up for granite rubble, the "scabblins" knocked off as waste from the granite quarries. In India Mr. Rawlinson states that there are embankments that have stood the monsoon rains for 3000 years on a much larger scale than Mr. Bateman proposed to construct in the Welsh mountains for the supply of London, one of which is now being constructed for the supply of Liverpool.

Percolation of Rainfall.—The first observations on this subject were made simultaneously by Dr. Dalton at Manchester, and M. Maurice at Geneva. The cylinder used by Dr. Dalton* was 10 inches in diameter and 3 feet deep, was open at the top, closed at the bottom, filled with earth, and sunk into the ground level with the surface, one side being less exposed for access to bottles—after the first year the surface of the soil was covered with grass; the observations extended over the three years 1796–1798. Percolation was 25·0 per cent. of the rainfall, and its difference was considered as evaporation.

M. Maurice† used a cylindrical iron vessel filled with earth; his observations extended over the two years 1796 and 1797, giving an average rainfall of 26 inches per annum, of which 39·0 per cent. percolated.

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* 'Mem. Lit. Phil. Soc.' Manchester, vol. v. part 2.

† 'Bibl. Universelle de Genève, Sciences et Arts,' t. i. Quoted by Dr. Gilbert, 'Minutes of Proc. Inst. C.E.,' vol. xlv. Part iii., p. 58, 1876.

In 1821 and 1822 M. Gaspain * made similar observations at Orange (South of France); the average rainfall was 28 inches, of which only 20 per cent. percolated.

For eight years, 1836–1843, Mr. Dickenson † kept a Dalton gauge at King's Langley. The cylinder was 12 inches in diameter, 3 feet deep, with perforated bottom, and receptacle for collection of drainage water; grass was grown on the surface of the soil, gravelly loam forming the land; the average rainfall was 26·61 inches. The mean rain of the eight years, from October to March, was 13·95 inches, of which 10·39 inches percolated, or 74·5 per cent. The mean rain of the same period, between April and September, was 21·67 inches, of which only 0·90 inch percolated, or 7·1 per cent., giving a total mean for the eight years of 11·29 inches percolated per year, or 42·4 per cent.

M. Risler ‡ estimated percolation from 1867 to 1868 at Calèves, near Nyon, Switzerland, by gauging drains 1·2 metre deep, in a compact, impervious soil, surface cropped as usual; the average rainfall was 41 inches per annum, of which 30 per cent. percolated, and 70 per cent. was evaporated, including that due to vegetable growth.

M. Ebermayer § made some interesting observations between March, 1868, and February, 1869, as to the amount of percolation; in open and forest ground, at four stations in Bavaria, the cylinder used was made of zinc, with an area of 1 square foot, and 1, 2 or 4 feet (French) deep, filled with adjacent soil, and exposed to air and rain for some time to acquire normal physical characters.

Taking the result in percentages of the rainfall for the winter half-year, October to March, 72 per cent. of the rainfall percolated in open ground 1 foot, 80 per cent. in the forest without litter, and 86 per cent. with litter, while in the

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* 'Cours d'Agriculture,' t. ii. p. 116.

† 'Journal Agricultural Society,' vol. v.

‡ 'Archives des Sciences de la Bibliothèque Universelle,' Sept., 1869.

§ Quoted by Dr. Gilbert, 'Minutes of Proc. Inst. C.E.,' vol. xlv. Part iii., p. 59, 1876.

summer half-year, April to November, the figures are 23 per cent., 57 per cent., and 75 per cent. respectively, the most striking diminution in summer percolation, as against that of winter is that on open ground, being less by 49 per cent., while the difference in forest land with litter is only 11 per cent. In July only 11 per cent. of the rainfall percolated 1 foot, and 7 per cent. to 4 feet, while in forest ground with litter 58 per cent. percolated 1 foot, and 34 per cent. 4 feet.

Percolation through Soil. Inches (English).	Mean of Four Stations, March, 1868—Feb. 1869.	Spring, March to May.	Summer, June to August.	Autumn, Sept. to November.	Winter, December to February.	Growing Period, April to September.
1 foot deep ..	20·01	5·22	2·26	4·41	8·13	5·40
2 feet „	18·08	5·35	1·62	4·08	7·06	4·90
4 feet „	19·41	5·86	1·09	4·09	8·36	4·69
Average rainfall	36·00	..	..	..	..	..
Forest without Litter.						
1 foot deep ..	18·56	4·99	4·12	3·96	5·49	7·62
Forest with Litter.						
1 foot deep ..	20·63	5·69	5·77	3·84	5·34	9·69
2 feet „	21·48	5·75	5·42	4·52	5·78	9·84
4 feet „	16·54	6·00	3·00	3 48	4·07	7·13
Average rainfall	27·5	..	..	..	..	..

Ebermayer quotes Professor Woldrich, as having determined the amount of percolation near Vienna and Salzburg, through turf and bare ground; in January the difference was least, in May more than twice as much percolated through bare earth than through turf, at both localities. From June 16–30, at Salzburg, there percolated through 2 feet,

2·12 (English) inches through bare earth;
0·02 „ „ turf.

The maximum difference was in June and July, and least in

autumn and winter. Ebermayer concluded that in the summer half-year forest soil was the moistest, bare open ground next, and turf the driest.

An elaborate series of observations has been carried on at the Experimental Farm at Rothamsted, Herts, between September 1, 1870, and August 31, 1875, by Dr. Gilbert and Mr. Lawes. Their gauges were constructed around a block of natural soil, which was carefully underpinned and built round without any disturbance of the ground. The area of their gauges is 1-1000 of an acre, the depths being, respectively, 20 inches, 40 inches, and 60 inches. During the period of 5 years observed, 36·8 per cent. of the rainfall percolated into the first, 36 per cent. through the second, and 28·6 through the third.

The yield of springs, and the volume of water in rivers fed by springs, have been found by Mr. Charles Greaves, M. Inst. C.E., to be more closely dependent on percolation through the soil than on mere rainfall. The experiments were carried out in the River *Lea*, at the intake of the East London Waterworks immediately below that of the New River Company. These gauges were constructed on the principle of the "Dalton Gauge," *i.e.*—a ground gauge in October, 1851, consisting of "a strong slate, open-topped, water-tight box, or tank, with an area of 1 square yard, and 1 yard deep, has connected to the middle of its bottom a lead pipe, which is led to another fixed vessel with a close bottom set upright as a receiver, and with its base placed several feet below the tank; a glass gauge-pipe is fitted to the side of the receiver, with stop and outlet cocks and a graduated scale, and the whole of the receiver is easily protected from frost. The slate tank is sunk into the ground. The inside of the bottom is slightly coned with cement to the mouth of the outlet pipe, and the tank is filled with soil or earth to within 2 inches of the top. The soil is turfed over, kept level, and the grass is occasionally cut; nothing is done to tighten the soil, and worms are sometimes seen. The water in the receiver never reaches the level of the bottom of the

tank, the soil of which is under-drained."* All rainfall sinks into the tank, and there is no overflow; the soil has once been taken out of the tank and replaced. Another tank of the same construction was filled with fine sand in 1860, to determine the actual maximum of percolation; and a similar tank, but only 1 foot in depth, was fitted up, at the same time as the ground gauge, as a rain gauge, with a similar area. The receiver of the ground and sand gauge is $\frac{1}{20}$ of the area, and of the rain gauge $\frac{1}{12}$.

In addition to these gauges Mr. Greaves has constructed a water or floating gauge, to show the free evaporation from a surface of running water. This was constructed in 1859, and is a yard square and a foot deep; the water surface within it is always kept below that of the river.

The gauges at Lea Bridge are situated 10 feet above Trinity High Water Mark,† and are read at 9 A.M.; the average rainfall for the period 1864 to 1870 was 24·486 inches, that of twelve stations, recorded by Mr. G. J. Symons, in the neighbourhood, 23·934, which agrees closely. Only in three years, viz., in 1861, 1864, and 1868, the annual evaporation from water exceeded the rainfall; in 1870 it was the same, and in the remaining years rainfall was in excess; averaging, the year's evaporation from water was 77·77 per cent. of the rainfall. In 1861, 1864, and 1868, when evaporation exceeded rainfall, the inability to store water and the loss of store was severely felt. In seven months of 1868 no less than 11·375 inches of water, stored in inclosed open areas, disappeared by simple evaporation; in five months of 1870, 10·625 inches; in five months of 1864, 9·375 inches; in seven months of 1861,

* 'Min. Proc. Inst. C.E.,' vol. xlv. 1876.

† Trinity High Water Mark, at Lomers Quay, Billingsgate, is 12·36 feet above Ordnance Datum; at the Hermitage Entrance of the London Docks, it is 12·53 feet above, which is taken as the standard of comparison. The highest high water at London Bridge observed by the Ordnance Survey was 13·45 above Ordnance Datum, the lowest low water being 8·25 feet below it, or 11·75 feet above the Thames Tide Gauge zero, which is 20 feet below Ordnance Datum. To reduce Trinity to Ordnance levels, therefore, add 12·50 feet, *i.e.*, Lea Bridge Ganges are 32·50 above Ordnance Datum.

9·125 inches. The evaporation from a surface of water varied only from 26·933 inches to 17·332, or as 7 to 4½ in fourteen years. The variation in rainfall was as 2·33 to 1, being 37·166 inches in 1872, as compared with 15·891 in 1864. The annual percolation through ground varies as 3½ to 1, the greatest being 12·587 inches, the least 3·761 in fourteen years. The percolation through sand varies as 7 to 4, being 30·050 inches in 1872 and 12·636 in 1864.

The greatest percolation is found after frequent thaws of small falls of snow, and generally after thaws percolation is great, while in summer it is practically absent; five times there was no percolation for seven continuous months, and only in one year, 1860, was there percolation every month. Sometimes excess or absence of percolation may exert an influence for a twelvemonth, but though "a wet winter will give abundant springs in the following autumn," its influence will be obliterated if the autumn is followed by a dry winter.

In winter the evaporation from the ground is in excess of that from water; in summer it is the reverse, while percolation is nil. When the percolation from December to February has been small, the volume of rivers fed by springs will fall off in the succeeding September and October, being fed only by the rainfall at the time; and these considerations apply still more strongly to intermittent springs, entirely fed by previous percolation.

The following table gives the average of Mr. Greaves' results for fourteen years:

Rain.	Percolation Ground.	Evaporation Ground.	Percolation Sand.	Evaporation Sand.	Evaporation Water.
25·721	7·582	18·138	21·406	4·313	20·613

Of the 7 inches percolating annually, no less than 6 inches is absorbed in the six months ending March 31st. This determination rests upon experiment made on soil covered with vegetation, growing on soil placed artificially.

The following artificial table, prepared by Mr. Greaves, gives the figures that may be expected in an average year:

	Average Rain.	Average Sand.	Percolation Ground.		Average Rain.	Average Sand.	Percolation Ground.
October ..	3·000	2·375	0·750	April ..	1·500	1·250	0·250
November	2·125	2·000	1·250	May ..	2·250	1·875	0·125
December	2·000	1·375	1·250	June ..	2·125	1·625	0·125
January ..	2·000	1·875	1·250	July ..	2·125	1·125	0·125
February ..	1·375	1·250	0·750	August ..	2·625	2·000	0·125
March ..	1·750	1·625	0·750	September	2·125	1·625	0·250
Total ..	..	..	6·000	Total ..	..	..	1·000

Where rain falls upon perfectly porous soil, underlaid by impermeable deposits, or on a fully *saturated* permeable formation, in which, from the horizontal disposition of the strata, and from their being either surrounded by impermeable strata, or so near to the sea-level as to cause a practical absence of outfall, the *water-line* or plane of complete saturation is found at a few inches or feet from the surface This is well seen in the alluvial gravels lying at the bottom of most valleys, including that of the *THAMES* at London, the *Irwell* at Manchester, the *RIBBLE* at Preston, and in tracts of blown sand, as at Southport in Lancashire and Rhyl in North Wales.

In sandstone and limestone hills intersected by valleys, the saturation-plane is found to be slightly above the lowest level at which the deepest valley intersects an impermeable stratum forming the floor on which rests the water-bearing rock. Where bands of permeable and impermeable rocks alternate, each porous band contains a separate sheet of water, which flows down the dip-planes of the strata, confined by an impermeable layer above and below. Such water flows with the head due to the difference of vertical level of the area of outcrop to that of the area of discharge, less the frictional resistance caused by the fragments of rock through which it passes. When the facilities for the discharge of a volume are less than the quantity capable of being received, the porous

rock will be full, up to the roof formed by the impermeable layer above, which is always the case when all outlet is stopped by faults throwing in an impermeable barrier, or by the dip carrying the strata beneath the sea-level.

Porous rocks carrying down water in this manner may be regarded as underground conduits, the *depth* of which is the thickness of the permeable rock, the *width* is that of the extent of the strike or horizontal extent of the rock, and the *inclination* that of the *dip* of the rock. Good examples of such a succession of water-bearing horizons exist in the upper *THAMES* Basin, sections* across which have been published by Professor Prestwich, F.R.S., showing the various sheets of water occurring around and above Oxford. Proceeding from west to east, from the Cotswolds, 900 feet above the sea, it will be noticed that the Inferior Oolite composing their mass is only fully saturated at the base, and the water following the dip escapes at Syreford Spring, 599 feet above the sea. Still further eastwards, the water contained in the Great Oolite, supported by the Fuller's Earth, does not rise to the top of that rock until it passes beneath the Forest Marble east of Northleach, when it parts with some of its volume at the Seven Springs, and even then the water does not rise to the top of the permeable rock until it has been carried some distance under the hill. Eastward, the Fuller's Earth thinning out, the two water-zones formed by the Inferior and Great Oolites unite, and pass under the thick impermeable Oxford Clay, between the rivers *Windrush* and *Isis*, underlying the permeable Coralline Oolite, which passes under the Kimmeridge Clay east of Oxford at an increased inclination, and is succeeded by successive beds of water-bearing strata, all fully saturated to the extent of their mass. From these considerations it will be seen, that where porous rocks form the surface of an inclined district intersected by

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* Plates accompanying Report of Royal Rivers Commission, and 'Geological Conditions affecting the Water Supply to Houses and Towns.' Oxford and London: James Parker & Co. 1876.

valleys, the base of such rocks will alone be fully saturated; that when such rocks pass under and between impermeable layers, the portion lying nearest to the outcrop will probably not be fully saturated; or, in other words, the gradient of the saturation-plane will be somewhat less steep than the dip of the strata; when, however, the dip is considerable, the rock is fully charged, and the gradient of the one corresponds to the dip of the other.

In the case of large masses of porous rock forming the surface, as Chalk or New Red Sandstone, there is a tendency to a quâ-quâ-versal gradient, the water absorbed at the outcrop being added to by additional percolation from the ground at the top of the hill, together forming a volume greater than the area of outfall can run off, and a local accumulation of water takes place along a line roughly corresponding to the ridge of the hill.

In sinking a well, or boring into such a mass, the level of the water, or plane of saturation, will be found to vary within certain limits, being governed by the amount of rainfall absorbed. This level, after extensive pumping, is artificially and locally lowered, but, on the cessation of pumping, the original level is restored by a sufficient interval of rest, provided the volume abstracted annually is not more than is absorbed from rainfall. The difference between the *rest-level* and the pumping level is in some wells as much as 100 feet; the area of exhaustion of water in the rock around a well resembles in shape an inverted cone, the apex of which is formed by the point at which the water is abstracted. When pumping has been excessive, and the water-level so lowered that the pumps have to be altered and the intake placed at a lower level, the height of the cone is not only increased, but its base widens, laying a larger area of ground surface under contribution. The area of supply of most wells of this class is a circle in which the well is the centre; at each successive lowering of the pumps a larger and concentric circle of supply is added to the central one. In many wells the water is found to become softer after pumping for a time, and then

after excessive pumping to gradually again increase in hardness. This is easy to understand if it be considered that the central portion had its salts gradually removed by the passage of water through it, and that afterwards excessive pumping laid a fresh area of contribution under supply in which the salts were not exhausted.

Sandstones and grits consist of rounded grains of various degrees of coarseness. If a block of sandstone is gradually and partially immersed in water, it will be noticed that the water is not *absorbed into the grains of stone*, but rises up in the rock by capillary attraction exerted by the individual grains of sand, causing the cavities which exist between the grains to be readily filled. The coarser the grain of the rock the larger the cavities, and the more freely will water pass through it.

According to experiments of Mr. Isaac Roberts, F.G.S., average Liverpool New Red Sandstone will take up $\frac{1}{22}$ of its own weight of water, of which $\frac{1}{10}$ will drain away through the influence of gravity, while the remaining $\frac{1}{12}$ will be held in the cavities of the stone by capillary attraction. Mr. I. Roberts has also made some interesting experiments as to the effect of pressure on the quantity of water that will pass through a square foot of stone $10\frac{1}{2}$ inches in thickness, of average coarseness, with the following results:—

At a pressure of	10	lbs.	to the	square	inch,	$4\frac{1}{2}$	gallons.
„	„	20	lbs.	„	„	$7\frac{1}{2}$	„
„	„	46	lbs.	„	„	19	„

The increase being nearly directly as the pressure.

Mr. I. Roberts, in a paper read at the Dublin meeting of the British Association, gave the results of his experiments with filtration of sea-water through Triassic sandstone. Cubes of sandstone from the Everton Pebble Beds 12 by 12 inches square, and 13 inches high, were selected, and 15 gallons of water from the *MERSEY* at Rock Ferry passed through them. The filtrate of the first two fluid ounces that passed through the first cube gave 80·8 per cent. of chlorides

removed. The water was then allowed to gradually pass into a second cube, and then into a bottle; at the fourteenth filtrate, only 80·51 per cent. of chlorides were removed, and the last drops were of the same composition as ordinary sea-water, the filtering power of the cubes being exhausted. The author has ascertained that the process of filtration is purely molecular and not chemical, and suggests the affinity of the capillary attraction of the grains of sandstone is greater for chlorides than for water.

The water stored in microscopic interstices between the grains of quartz making up the sandstone is stated to be 0·733 gallon per cubic foot; which water, on the sandstones being tapped by pumping from wells or boreholes, produces a current towards the point of abstraction, retarded more or less by frictional resistance and capillary attraction; which current in sectional form assumes that of an inverted cone, the apex resting on the point of abstraction, the base on the permanent water-level, which gradually lowers as pumping exhausts the supplies, unless they are replenished by absorption of rainfall of equal amount at the surface.

The Table on p. 19 shows the varying quantity of water held in the pores of various rocks, per cubic foot.

The figures given in it afford a means of obtaining an approximation of the storage capacity of a given thickness of rock, when the thickness of the water-bearing stratum is known, and the depth to the plane of complete saturation. Thus, supposing the Pebble Beds and the underlying Lower Mottled Sandstone to be, as at Bootle, near Liverpool, 1500 feet or 500 yards thick, and the water-level to be 25 yards beneath the surface, a total volume of water will be contained in a square mile of such rock of $500 - 25 \times 61{,}952{,}000$ gallons, or 29,426 millions of gallons.

One inch of rainfall equals 1 gallon* falling over 2 square feet, or 22,427 gallons per acre, or 14,355,280 gallons per square

* One gallon of water equals 277·274 cubic inches, 70,000 grains, or 10 lbs.; 224 gallons make a ton; one cubic foot equals 6·232 gallons, or 1000 ounces, or 62·5 lbs.

	Specific Gravity.	Weight of a Cubic Foot in Pounds.	Number of Feet to the Ton.	Holds Gallons per Cubic Foot.	Gallons per Cubic Yard.	Gallons per Acre One Yard Thick.	Gallons per Square Mile One Yard Thick.
Water, Rain	1·000	62·5	35·8	6·23	168	..	..
„ Sea	1·026	64·1	35·0	6·23	..	..	..
Ice	·940	58·7	..	..	..	..	..
Sand	1·886	118·0	19·2	2·00	54	261,360	167,270,400
Chalk	2·315	145·0	15·4	2·00	54	261,360	167,270,400
Bath Oolite	1·839	115·0	19·5	1¼ (10 pints)	33	..	..
Magnesian Limestone	2·316	145·0	15·4	1¾ (14 pints)	47	..	..
Good building Sandstone ..	2·266	142·0	15·8	0·625 (5 pints)	17	..	..
Pebble Beds	2·506?	151·0?	14·4?	0·733	20	96,800	61,952,000
Granite	2·662	166·0	13·5	0·185 (1½ pints)	5	24,200	15,488,000

C 2

The specific gravity of a body is its weight, in proportion to an equal bulk of water. The weight of a cubic foot of water at the temperature of 60° is 1000 ounces (avoirdupois). The specific gravity of a body (water being 1000) shows the weight of a cubic foot of that body in ounces.

mile. Such a rainfall spread over a year of 365 days gives a daily average of 62 gallons per day per acre, or 40,000 gallons per square mile, or, with an annual absorption of 10 inches of rainfall, a daily volume of 400,000 gallons per square mile.

From these figures it will be apparent that the block of sandstone a mile square and 500 yards in thickness must have required a daily absorption of 400,000 gallons for more than 200 years before it became filled to its present level, and that therefore, if the yield is not to be diminished of any well sunk in the area, the quantity pumped annually must not exceed the volume annually absorbed.

In wells and borings of the *artesian* class, in which a permeable rock is penetrated, receiving its supply of water from a distant district, the water will rise in the tube to a height due to the pressure produced by the height of the in-take, less the friction produced by the passage of the water through the pores and joints of the rock: the height to which the water will rise forms the *artesian rest-level*, and the slope or inclination which it is found to have in a series of borings across country is the *artesian gradient.* Local pumping at any one of these points will produce a local depression around each well pumped, the level of which may be termed the *artesian pumping level.* If three or more pipes were carried down to three or more distinct water-bearing strata drawing their supplies from distinct areas of in-take at different levels, the artesian rest-level of each would differ in height, and all would vary from the *rest-level* of the water in the porous rock forming the surface which is not at pressure.

After long-continued rains, the rock becomes fully saturated, after which no more water can be absorbed, and all additional supplies pass off as floods, as absolutely as if the precipitation took place on an impermeable formation. The capacity of a rock for storing water varies with the texture and character of the materials composing it. In the grits and sandstones of the Carboniferous and New Red

Sandstones, and in the Cretaceous Greensands, the water is stored in the interspaces between the grains, in the manner in which water is stored when poured into a pail previously filled with shingle; the difference of volume of water in a pail filled with water, and filled with shingle and water, representing the capacity of a pailful of shingle to store water. A pail filled with sand and water would store a still larger quantity of the latter, from the more numerous interspaces between the grains of sand, which is still found to be the case, though to a more limited extent, where the grains of sand, by consolidation, have passed into the form of sandstone. In limestones the quantity of water held by a given mass of rock also varies with its compactness, part of the water held having been absorbed by cracks, joints, and fissures in the rock, whilst the remainder of the water held in the mass occurs between the particles, for the retention or abstraction of which there is a constant struggle between capillarity and gravity; and, though the water is received with great rapidity, it is parted with with exceeding slowness. It is important to distinguish between the amount of *storage capacity* in permeable rocks, from the actual volume annually *absorbed* from rain falling over its outcrop.

Subsoils formed of porous sands, loams, or peat-moss, do not discharge any of the rainfall they receive until they are fully saturated, and overflow at their lowest point as a spring or stream. When there is no outfall, and the rainfall is excessive, the water rises above the level of the soil, and the ground is covered with a lagoon or marsh. When there is a slight outfall, but not sufficient to carry off the whole of the rainfall not absorbed by the soil, the ground becomes flooded, and the level gradually diminishes as the water runs off. The effect of under, or arterial drainage is to artificially lower the outfall. If the level of the artificial outfall is placed at half the depth of the porous soil, the ground beneath this level will still remain fully saturated, and incapable of receiving any further additional volume. Before the artificial outfall was made the upper half was in the same condition, and if

the drains or sluices are sufficient to take off the whole of the balance of rainfall not absorbed by the soil below their level, the upper half will be kept dry, and capable of absorbing any excessive rainfall that the drains cannot carry off.

The effect of drainage works is therefore to temporarily check the violence of floods, the good effect directly increasing with the depth of the drains, leaving, as they do, an increased cubic content of ground to be saturated. The effect will be modified by the comparative steepness of the angle of the ground over which the water flows, and its relative porosity. So soon as the ground is restored to its original saturated condition, the drainage works, where an original outfall existed, exercise no effect, as that portion of the flood, if any, carried off by the drains formerly flowed away with the large volume still discharged by the surface.

CHAPTER II.

COMPOSITION OF WATER.

*Composition of Rain-water.**—The results of analytical examination of samples of rain show that this kind of water, even when collected at a distance of more than 25 miles from any large town, as in the example from Rothamsted, near St. Albans, quoted by the Rivers Pollution Commission, is by no means so pure as one is apt to imagine, and actually contains more organic matter than is present in waters that have been subjected to an exhaustive natural filtration, by percolation through a great depth of strata; in fact, water derived from deep wells, or deep-seated springs, is far freer from organic pollution than the very best rain-water that can be collected from the roofs of houses. And this is not surprising when it is remembered that the atmosphere is the recipient of a vast amount of impurity derived from the respiration of animal life, the combustion of vast quantities of fuel, the fumes of manufacturing processes, fine particles of organic matter derived from animal and vegetable waste and decay, and zymotic germs. These matters in dry weather remain suspended in the air for weeks, are carried by the winds over the area of the country, until condensation of moisture, in the form of cloud and fog, takes place, and are entangled and imprisoned in the minute globules of water, which together form what we call cloud.

Half a pint of rain-water often condenses out of about 3373 cubic feet of air. This is the quantity of air a man breathes in 8 days, so that in drinking a tumblerful of such water, which has washed a dirty atmosphere, he swallows an amount of impurity which would only gain access to his lungs from respiration in 8 days.

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* This chapter is chiefly taken from the Sixth Report of the Royal Rivers Pollution Commission, 1874.

Dew and hoar-frost are condensed out of the stratum of atmospheric air nearest the earth, which of necessity contains more impurity than the upper regions where rain condenses, and it is therefore not remarkable that the continuous evolution of ammonia from manured land, and from putrescent animal matter, should cause these forms of water to be heavily charged with ammonia.

Water, in passing from the surface through soil, sand, gravel, or rock, takes up soluble inorganic or mineral matter, together with organic matter; by continued filtration through the ground the former is increased, while the latter is sensibly diminished, and, when the filtration is sufficiently great, altogether destroyed—oxygen combining with the injurious nitrogenous compounds, and the resultant acids with the alkalies of the soil—forming harmless nitrates and nitrates of soda and potash.

The artificial filtration of *THAMES* water through a thin layer of sand and gravel reduces the quantity of organic matter, 1 to 2 grains per gallon, to from $\frac{1}{4}$ to $\frac{2}{3}$ of that quantity. Waters leaving large residues on evaporating are unfit for domestic use, and are of no value for a large number of manufacturing purposes. This solid residue consists of mineral and organic matter, with which the water has become contaminated since its condensation from the atmosphere; this residue forms the "total solid impurity." From a sanitary point of view, the organic portion is of the highest importance, and various processes have been suggested for its determination.

Carbon.—The weight of "organic carbon," found in different samples of water, indicates the amount of organic matter with which the water is contaminated, but not the source, animal or vegetable, whence that carbon was derived. *Cæteris paribus*, the smaller the proportion of organic carbon, the better the quality of the water. A larger proportion of organic carbon than 0·2 part in 100,000 parts of water, when derived from vegetable matter, renders it slightly bitter and unpalatable, which is not the case with even a

larger proportion of organic carbon derived from animal sources, which exposes the consumer to infection when much more than 0·1 part of organic carbon is present in 100,000.

The smaller the absolute quantity of "organic nitrogen," and the less the proportionate amount as compared with organic carbon, the better is the quality of the water as regards present or actual pollution, and the less likely to contain any organic matters of animal origin. But it must be remembered that vegetable organic matter, as peat, is far from being destitute of nitrogen, but peaty matters after long exposure to atmospheric oxidizing influences lose carbon more rapidly than nitrogen, and thus increase the proportion of the latter to the former element.

Ammonia.—This mineral nitrogenous compound is generally present in potable waters, sometimes being derived from the atmosphere, 0·21 part in 100,000 occurring in a sample of London rain, sometimes from the decomposition of animal matter, 2·75 parts occurring in some shallow London wells, though rapidly converted into nitrates and nitrites under oxidizing influences; but in some cases the ammonia found in waters from the Chalk beneath the London Clay is derived from the decomposition of nitrates.

Ninety-seven per cent. of the combined nitrogen is converted into nitrates in percolating through five feet of gravel. The soakage of sewerage into a porous soil in hot climates is the cause of large quantities of nitre being generated, which in many Indian villages is collected for manufacture. When a village is deserted,* the formation of nitre ceases.

Animal matters dissolved in water, and carried into lakes, rivers, and streams, undergo oxidation slowly, but in the pores of an open porous soil it is rapid, and when complete they resolve into mineral compounds; the carbon is converted into carbonic acid, the hydrogen into water, the nitrogen into nitrates and nitrites, which remain dissolved in water

* Dr. Palmer, 'Journal Chemical Society,' vol. xxi. p. 318.

for a long time, and afford a record of "previous sewage contamination."*

Chlorine.—It is always in combination with other elements, and chiefly with sodium, as common salt. According to Dr. Angus Smith, it varies from 0·12 part per 100,000 (London rain) to 5·46 on the sea-coast of the West of England.

Some of the mineral substances which occur in solution in potable waters communicate to the latter the quality of *hardness*, the chief hardening ingredients being salts of lime and magnesia. Hard waters decompose soap, and cannot be efficiently used for washing, curdy and insoluble compounds being formed containing the fatty acids of the soap, which is decomposed, and the lime and magnesia of the salts. So long as this decomposition goes on the soap is useless as a detergent, and it is only after all the salts have been decomposed at the expense of the soap, that the latter begins to exert a useful effect, and an addition of soap produces an agitation in the water, and what is known as a lather.

Each degree of hardness in water indicates the destruction and waste of 12 lbs. of the best hard soap by 100,000 lbs., or 10,000 gallons, when used for washing. A sample of water containing 1 lb. of carbonate of lime, or its equivalent of other hardening salts, in 100,000 lbs. is said to have one degree of hardness. When the hardening effect is due to bicarbonates of lime and magnesia, these salts are decomposed in boiling water into free carbonic acid which escapes, and insoluble carbonate of lime and magnesia. The hardness thus removable is designated *temporary hardness*, whilst that remaining, due chiefly to sulphate of lime and magnesia, is termed *permanent* hardness. The *total* hardness is made up of the temporary and permanent hardness.

Hard water not only acts injuriously in washing, through the waste of soap, and to the skin, by clogging the pores with curdy matter; but, when employed in the generation of

* Rivers Pollution Commission, 6th Report.

steam, forms dangerous and troublesome incrustations in the boiler, especially where the temporary hardness is very great.

It is often stated that figures will prove anything, and when statistics of the death-rate in towns supplied with water of different degrees of hardness are examined, the result would certainly appear to be that hard waters were the most wholesome, but the high death-rate of Bolton, Glasgow, Manchester, and Greenock is not due to the pure soft water drank, but to the density of population, the utter disregard to sanitary laws, and the lack of care given to the children of the manufacturing towns.

Rivers Pollution Commission. Sixth Report, p. 194.	Number of Cities and Towns.	Average Population of each.	Hardness of Water. Parts per 100,000.	Average Rate of Mortality.
Table				
I.	26	73,366	Not exceeding 5°	29·1
II.	25	81,655	5° to 10°	28·3
III.	60	44,797	Above 10°	24·3
	London	3,254,260	16° to 32°	24·6

The hardness of rain-water varies from 0·0° to 10°; the latter degree is only attained near the sea-shore when the wind is from the sea and during rough weather, and the average hardness of rain-water may be taken at 0·62°.* The sample giving 10° of hardness was collected on the Land's End, 100 feet above the sea, and it contained no less than 21·8 in 100,000 parts of water. The average proportion of chlorine found in rain-water by the Commissioners was 0·23 part in 100,000 parts of water.

Hard water may be softened by—

1. Distillation. Distilled water—vapid from deficient aeration—used in ships of Navy.

2. Carbonate of soda. 1 cwt. of soda = effect of $4\frac{3}{4}$ cwt. of soap; 10

* Multiplying by 7, and then moving the decimal point one place to the left, transforms the hardness in the tables of the Commissioners to Clark's scale.

gallons of THAMES water 20° hardness requires waste of ¼ lb. of soap, or 12 lbs. of the best hard soap for each degree of hardness in 10,000 gallons of water used for washing.—Soda 12*s.* 2*d.* per cwt., while soap is 2*l.* 6*s.* 6*d.*

3. Boiling. 1000 gallons of water raised to boiling, and kept so for half an hour, take 2½ cwt. of coal.—Softening by boiling no less expensive than by soap.

4. Lime. To soften a quantity of hard water which requires 1 cwt. of lime, which costs 8*d.*, would require by other means:—

	£	*s.*	*d.*
4¾ cwt. of carbonate of soda	2	17	9
20¼ cwt. of soap	47	1	8

Dr. Thomas Clark, Professor of Chemistry in the University of Aberdeen, in a letter, dated October 30, 1867, to the President of the Rivers Commission, narrates that, being in London in the autumn of 1837, he accidentally saw a Parliamentary Blue-Book on the Water Supply, which he purchased for information to add to his lectures, these being given on the treatment of water for the supply of towns. Struck with the great hardness of the London chalk waters, he endeavoured to find a process to get rid of it, and took out a patent for the softening of chalk waters, in the specification of which degrees were first used to express the amount of hardness of a water. In 1851 a Government Commission, consisting of Professor Graham (afterwards Master of the Mint) and Doctors Miller and Hofmann, was appointed to examine the chemical quality of the waters proposed for the supply of the Metropolis, which reported that "this softened chalk water is entitled, from its chemical quality, to a preference over all others for the future supply of the Metropolis" (Report, page 44). The inventor proposed to treat the THAMES water by this process; but about the same time the late Robert Stephenson matured a plan for the supply of the Metropolis from the chalk under the London Basin, which was afterwards taken up by Mr. Homersham, who, in 1849, called Dr. Clark's attention to the applicability of his process to the softening of spring chalk water.

Clark's process is chemical, expelling chalk by chalk;

every pound of chalk consists of 9 ounces of lime, and 7 ounces of carbonic acid.

The 9 ounces of lime might be obtained by burning the chalk, as in a kiln. The 9 ounces of burnt lime might be dissolved in any quantity of water, not less than 40 gallons, which would then form lime water. In burning the lime the carbonic acid gas is driven off. This gas uncombined is volatile and mild; when dissolved in water under pressure it is termed soda water.

So little soluble is chalk by itself that 5000 gallons of water would probably be necessary to dissolve 16 ounces, but by combining it with 7 additional ounces of carbonic acid the chalk becomes readily soluble; when so dissolved it is called bicarbonate of lime.

So that chalk may be made soluble by either taking away its carbonic acid when it becomes capable of turning water into lime water, or by adding an extra dose of carbonic acid. Chalk spring water after being softened by this process is an exceedingly soft, pure water.

Caterham water is reduced from 21·2 of hardness to 4·4 by this process, at a cost of 27*s.* 6*d.* per million gallons; 100,000 gallons a day being softened by the addition of 10 gallons of lime water.

Cost of softening 1,000,000 gallons of chalk water having a temporary hardness of 20°:

	s.	*d.*
16 cwt. lime at 1*l.* per ton	16	0
Labour	7	0
Total	23	0

From this 2½ tons of whiting are produced, sold at from 10*s.*, the actual value of marketable whiting being 15*s.* per ton, which reduces the cost of softening to the consumer to 13*s.* per ton.

What is called the Porter-Clark process is a mechanical modification of the Clark process, by which the necessity of having settling-tanks occupying considerable space is done

away with. The most important works at present erected under this patent are those at the Edge Hill station of the London and North-Western Railway at Liverpool, where 15,000 gallons per hour, or more than a ton of water per minute, is softened. The apparatus consists of a tank for the hard water; a lime-water tank, where the water passes up through the lime, which is agitated by the slow revolution of machinery; and a mixing-tank, in which the chemical action of the lime water is promoted by a brisk agitation kept up by revolving grids, driven by a small steam-engine. After the reaction the water becomes milky, and is passed through filters consisting of a series of plates alternating with layers of cloth. The Edge Hill Works only occupy 40 feet by 25 feet.

In regard to their general fitness for drinking and cooking, the Rivers Pollution Commissioners classify waters in the order of their excellence, in respect to wholesomeness and palatability, as follows:—

Wholesome	1. Spring water,	Very palatable.
	2. Deep well water,	
	3. Upland surface water,	Moderately palatable.
Suspicious	4. Stored rain water,	
	5. Surface water from cultivated land,	
Dangerous	6. River water which sewage gets access to,	Palatable.
	7. Shallow well water,	

The value of spring and deep well waters is not merely due to their greater intrinsic chemical purity and palatability, but to their being peculiarly suited for domestic supply from their almost invariable clearness, transparency, and brilliancy, and their uniformity of temperature throughout the year, rendering them cool and refreshing in summer, and preventing their readily freezing in winter; and their utilization and conservation appear to be a matter not only worthy of inquiry, but one of national importance, and to demand Imperial legislation.

The Commissioners state that only water derived from

De Rance's Water Supply

Stanford's Geog.l Estab.t

London; Edward Stanford, 55, Charing Cross, S.W.

wells more than 100 feet in depth, and from deep-seated springs can be considered reasonably safe, for in these the organic matter contained in the water is rapidly oxidized in percolation through porous and aerated soil and permeable rock.

Upland Surface Waters from Igneous Rocks.—All the South British samples analyzed by the Rivers Pollution Commission were taken from Cornwall and Devon. The total hardness from a stream at Gazelan Clay Works, and of water supplied to Devonport from Dartmoor, was only 0·8, and of a mountain stream above St. Neot's 0·9. The hardest sample was only 2·6 from the *TEIGN* at Old Wheal, Exmouth. Chlorine ranged from 1·25 to 2·10. Previous animal contamination there was none. "Igneous rocks undergoing the process of weathering very slowly contain but mere traces of matter soluble in water, and afford excellent gathering-grounds for the rain falling upon them," of which a very large proportion flows off. Much ground of this sort is, however, covered with peat, the vegetable matter of which is slightly soluble in water, giving a brownish colour and a bitter taste, but is only deleterious to a moderate amount.

Upland Surface Waters from Metamorphic, Cambrian, Silurian, and Devonian Rocks.—The average hardness of 81 samples is 2·5; the minimum was the water of Bala Lake, 0·4, the maximum the water supplied to Ilfracombe from Slade Valley. The *Banw* and *Vyrnwy* in flood had only a hardness of 0·7 part per 100,000. These formations are nearly as insoluble in water as the igneous rocks, which they also resemble in being slightly absorbent. Most of the rain which falls upon them neither evaporates nor disappears beneath the surface, but flows off rapidly as rivulets and streams, and has consequently but little time to take up soluble impurities. The total solid impurity varies from 2·14 parts per 100,000 parts or 1·5 grain per gallon, in the waters of *Measand* brook, Cumberland, to 12·48 in the 100,000, or 8·74 grains per gallon in the Slade Valley water for Ilfracombe.

When Mr. Bateman's scheme for the supply of London

from the *SEVERN* was before the Duke of Richmond's Commission, it was considered desirable to analyze the waters of Bala Lake in order to ascertain the effect of storage in large reservoirs, analogous to those proposed to be constructed, and Dr. Pole, F.R.S., was instructed to examine the district, and collect the samples. He describes the hills as being often covered with peat, cut and burnt for fuel, causing the streams to be brown-stained in rainy weather. The lake at the time of his visit (2nd July, 1867) was low, but little water flowing in or out. The Bala and Dolgelly Railway was then constructing on the south bank, the level of the rails being only 2 feet above the flood-level, and about 6 or 7 feet above the drought-level, which he points out as a fatal obstacle to the raising of the lake artificially for the water supply of Liverpool, as recommended by Mr. Rawlinson, C.B., in 1846, and afterwards by the late Mr. Duncan, the Liverpool Borough Engineer. An analysis made by Professor E. Frankland, F.R.S., and Dr. Odling, F.R.S., gave :—

Total solid impurity ..	2·786	Hardness, temporary ..	0·1	0·4
Gases	2·036	„ permanent ..	0·3	

Dr. Frankland states that none of the samples of Welsh and Cumberland waters contain more than 0·35 part of organic carbon, in 100,000 (with the exception of the *Upper Clywedog*), their colour being "doubtless, due to peaty matter in solution, and it is believed that such peaty matter is to a great extent deposited or otherwise got rid of when the water is stored for some time in a lake or reservoir," which he considers confirmed by the clearness of the water from the lakes of Thirlmere, Haweswater, and Ulleswater, which contains at the maximum only 0·194 in 100,000 of organic carbon, and Bala Lake, which contains 0·227 part. Dr. Frankland adds, that lakes cannot exert this purifying action when the peaty matter is in excess; thus the effluent water of Loch Ness and numerous other Scotch lakes is of a deep yellow-brown colour; and remarks, that though peaty matter dissolved is not positively injurious, as it contains

organic nitrogen, it cannot be pronounced absolutely innocuous, and that water intended for domestic purposes ought not to exceed the proportion of organic carbon found in the Glasgow supply from Loch Katrine, *i.e.*, 0·256 part per 100,000. In the Welsh water the largest amount of organic carbon occurred in the *Upper Clywedog* (viz., 0·544), though this water "is perfectly colourless, the peaty matter having been blanched by the fine suspended detritus from the Dwngwm lead mines." This process of removal of colouring matter from water is seen on a magnificent scale in Switzerland, where Alpine torrents carrying the fine mud produced by the attrition of glaciers upon rocks enter the lakes milky and foul, but, having deposited their suspended matter in these reservoirs of subsidence, emerge clear and transparent, and of that magnificent blue-green tinge (properly belonging to absolutely pure water) which is so much admired in the *RHONE* as it flows from the Lake of Geneva, and in the Limmat leaving the Lake of Zurich." Dr. Frankland further points out the clarifying effect of the mines' detritus flowing into Ulleswater and Coniston Lakes, extending for some miles from the influent stream, the accuracy of which fact I have had many opportunities of verifying, and he considers that such streams flowing into artificial lakes would be a direct benefit. The fine material exercises the clarifying effect, but the coarser *debris* should be collected and arrested in settling-tanks as suggested by Dr. Pole, F.R.S.* The preponderance of the proportion of organic carbon over organic nitrogen points to the exclusively vegetable origin of the organic impurity of these waters.

Spring Waters from Granite and Gneiss.—The average total solid impurity is 5·94, average hardness 3·0, the minimum impurity and hardness being at the Rabat Fountain at Balmoral, which also had the minimum temperature of 6·5 C. The highest temperature being the springs at Dartmoor Supply, Dartmoor, of 12·5, their hardness is only 2·1. The

* Appendix to the Minutes of Evidence, Royal Commission on Water Supply, 1869, p. 21.

maximum hardness is a spring in the tunnel at Malvern, 5·6, with a temperature of 10·6. In waters issuing from a clay-pit at St. Austell the organic nitrogen and carbon was simply *nil*. They, like other springs, are cool and refreshing in summer, and in England are far removed from freezing in winter. The more disintegrated and weathered the rock, the freer will the water be from organic matter. Thus, the rock at Balmoral is but little weathered, that at Malvern more so, while the granite at St. Austell is turned into porcelain clay. The effect of this disintegration on the reduction of organic matter is shown by the following comparison :—

Proportion of Organic Elements in 100,000 Parts of Water.

Balmoral, water from Rabat Fountain	0·133
Malvern, average of two springs	0·043
St. Austell, average of two springs	0·008

Composition of Spring Water from Silurian Rocks.—The average of 15 samples gives total solid impurity 12·33, total hardness 6·8 ; the minimum hardness was at Bronydd Ty-gwyn only 1·5 ; the next being the South Spring on Llanbadarn 2·1, at Aberystwith, another spring here issues at 11·8 C., springs at Newtown, Montgomery, issue at 10·6 C. The whole of the solid matter in solution in these springs consists of harmless mineral salts, the organic matter is small, and the water adapted for drinking and washing.

Upland Surface Water from Calcareous portions of Silurian and Devonian Rocks.—Limestones of this age are sparingly distributed, and are exceedingly compact ; the waters from them, though harder than those from non-calcareous rocks, are far softer than the waters from the uplands of the Carboniferous Limestones. The samples analysed by the Rivers Pollution Commission are all Scotch, the average hardness being 8·6, chlorine ranging from 0·83 to 1·62.

Shallow Wells in the Silurian and Gneissic Rocks.—The samples analyzed were chiefly from Wales and Scotland ; the hardness ranged from 5·0 in Balmoral Castle well, and 5·1 town pump at Llanidloes, to 17·0 at pump in Pump

Court, Newtown, if the polluted well at the King's Head, Kendal, is excluded, the hardness of which is 41·5. The waters are clear and palatable, but not altogether satisfactory.

Shallow Wells in the Devonian.—Of the 29 samples 25 were in Cornwall or Devon, and only one was absolutely safe as a drinking water, though nearly all were clear, colourless, palatable, and sparkling. The hardness ranges from 5·0 to 55·7. The hardness is due to animal pollution; the softest waters were freest from organic impurity.

Unpolluted Waters from deep Wells in Devonian and Old Red Sandstone Rocks.—The hardness ranges from 3·6 at an artesian well at Ivybridge, to 32·5 at the Lunatic Asylum, Hereford, of which only 6·3 was permanent.

Unpolluted Water from Springs in the Mountain Limestone.—The softest water examined by the Rivers Pollution Commission was the so-called Chalybeate Spring of Buxton, which was 11·0, and contained no iron; the average of 12 samples was 17·4, while the hardest was also in the same district, the intermittent springs of Barmer Clough, 27·9, issuing at a temperature of 8°·6 C. The St. Ann's hot spring issues at 26°·9 C., and is only 14·7 degrees of hardness. The true springs of the Mountain Limestone are clear, colourless, palatable, wholesome, and suitable for all domestic purposes except washing. The pseudo-springs are less palatable, owing to the presence of peaty matter; these are in reality underground rivers, and the water assimilates itself to that collected from the surface of the same rocks. This is the case at the large stream at Malham Cove, forming the source of the *AIRE;* one of these springs, though only containing 16·20 parts per 100,000 of total solid impurity, contains 0·286 of organic carbon. The hardness of these springs averages 14·9, of which 4·1 is only permanent.

Surface Waters from Uplands of Non-calcareous Carboniferous Rocks (Yoredale, Millstone Grits, and Coal Measures) contain somewhat larger quantities soluble in water than are met with in the Igneous, Metamorphic, Cam-

brian, Silurian, and Devonian Rocks; but still the proportions are moderate, and these rocks form the best collecting surfaces in Great Britain. Being but slightly absorbent, they yield to the impounded rivulets and streams a large proportion of the actual rainfall. The total solid impurity in these waters varied from 4·58 in 100,000 parts, or 3·21 grains per gallon, in the water supplied to Lancaster from the Bleasdale Fells, to 15 parts in 100,000, or 10·5 grains per gallon, in the Leeds Water Supply from Eccup. The softest sample examined by the Rivers Pollution Commission was that from the Bleasdale Fells, which was only 0·9, with 0·99 of chlorine; the hardest was the water supplied to Preston, 9·0.* The mean hardness was 4°·7, including the water supplies of Bolton, Liverpool, Manchester, Oldham, Burnley, Leeds, Ripon, Knaresborough, Blackburn, Rochdale, Over-Darwen, Chorley, Sheffield, and Swansea. These waters are always well adapted for manufacturing purposes, and generally for domestic use. They are, as a rule, somewhat peaty, and therefore liable to be slightly unpalatable, and to be tinged with a yellow or brownish colour. They are generally turbid, and ought always to be subjected to prolonged subsidence, or preferably to sand filtration, before distribution to consumers. When the proportion of peaty matter causes the organic carbon to rise above 0·2 part in 100,000, or 0·14 grain per imperial gallon, the water is not fit for domestic consumption. This proportion is much exceeded in the water supplied to Padiham, Chorley, Bradford, and Buxton, and still larger quantities exist in a stream off the Allenhead Fells (1·025), and the head waters of the *WEAR* and *TEES*. In all these cases, however, there was no previous animal contamination, and all these waters are remarkably pure on this score, and it is also worthy of note that nearly all the hardness is permanent. When these peaty waters have naturally filtered through porous portions of the rocks, which have exerted a powerful

* The water at present supplied to Preston from the sources of the *Hodder* is softer than that of the Lancaster Corporation Supply.

oxidizing effect upon them, the water, issuing as springs, has lost a large amount of its organic impurity. The Rivers Pollution Commission shows that the average proportion of carbon to 1 part of nitrogen in upland surface water is 11·916, while, after slight oxidation by exposure in lakes or large artificial reservoirs, it is reduced to an average of 5·92, Windermere Lake (3·9) and Newcastle-on-Tyne reservoir (3·8) containing the least; while in springs giving off waters once peaty, the average was N : C as 1 : 3·26.

Shallow Well Waters, examined by the Rivers Pollution Commission, show that the rocks have the power of oxidizing water as it slowly filters through them. The waters from Yoredale and Millstone Grits varied in hardness from 2·9, in a well at Rawtenstall Wood (York), to 90·0, in a well at Gainford, near Darlington. The waters from the shallow wells in the Coal Measures varied in hardness from 3·4 at Sheffield (South Yorkshire Asylum), and 4·7 at Ogly-Hay, near Walsall, to 140·8, in a well sunk by the Local Board at Newbiggin-by-the-Sea. A large number of these were dangerously polluted, and the chlorine ranged high, 29·0 in one instance.

Unpolluted Waters from the Millstone Grit.—Only two samples were examined by the Rivers Pollution Commission, giving an average hardness of 14·9, about half of which could be reduced by Clark's process. In one of them, a well 360 feet, at Messrs. Ingham and Sons, Bradford, the water issued at a temperature of 12·8 C., and had, when first drawn, traces of sulphuretted hydrogen, which disappeared on exposure to the air. The Rivers Pollution Commission states it is present in many artesian waters of undoubted purity, and is probably due to the reduction of the sulphates in the water; the chlorine here was 3·23; at Glossop (Dinting Vale) it was 0·87. *Unpolluted Springs from the Yoredale and Millstone Grit* range in hardness from 2·7, source of the *Laver*, Ripon, to 26·0, Holme Well, Hawes, near Bedale. The spring flowing into the baths at Ilkley is 8·6, and its temperature 8°·3 C.

Unpolluted Water from Deep Wells in Coal Measures.—The total solid impurity was high, averaging 83·10, and average hardness was high, reaching 35·7, but no noxious constituents were present. These waters contain about twice the quantity of oxygen, carbon, and nitrogen contained in the Millstone Grit, but the Rivers Pollution Commission point out that, the Coal Measures abounding in organic matter, it is not surprising that these elements should be high.

The pure waters examined were those from the coalpits supplying Accrington and Blackburn.

	Total Solid Imp.	Chlorine.	Hardness.	
			Permanent.	Total.
Accrington (coalpit)	83·42	1·40	2·2	9·9
Blackburn („)	36·96	1·29	1·2	10·4
Bedlington (Northumberland) (coal-pit)	144·88	4·70	15·3	43·5

Previous animal contamination in these samples was absent. As a rule Coal-Measure waters are slightly chalybeate, but are wholesome waters, though unfit for washing purposes from their hardness.

Magnesian Limestone.—Composition of shallow wells.—The waters examined by the Rivers Pollution Commission were all more or less polluted; total solid impurity ranged up to 108·88, and total hardness 88·6 (well at Darrington, near Pontefract), and were considered useless for washing purposes. The Rivers Pollution Commission give analyses of Sunderland and Pontefract water supplies, and from a well at Mansfield, Woodhouse, which they state to be derived from this formation. The average total solid impurity was 61·14, hardness 43·8. The Sunderland water was stated to be excellent for cooking and drinking; its hardness is only 14·7, which is nearly all permanent. Dolomite (double carbonate of lime and magnesia) imparts to 100,000 lbs. of water 5·89 lbs. of lime and 3·96 lbs. of magnesia.

Permian and Trias.—The average amount of hardness of the water of the deep wells of the New Red Sandstone, as tabulated by the Rivers Pollution Commission, being 17°·0, and of the springs from the same formation no less than 18°·8, the relation of the hardness of water to the rate of mortality of the persons drinking it becomes a matter of great importance.

The Commissioners give three tables of statistics that bear directly upon this point.

From Table I. it appears that in twenty-six towns, inhabited by 1,933,524 persons, supplied with water not exceeding 5° of hardness, the average death-rate was 29·1 per 1000 per annum.

From Table II. we learn that in twenty-five towns, inhabited by 2,041,383 persons, drinking water of more than 5°, but not exceeding 10°, the average death-rate was 28·3 per 1000.

In Table III. we find that sixty towns, with an aggregate population of 2,687,846, drinking water of more than 10° of hardness, the average death-rate was only 24·3.

Of the towns in Table I., none are supplied from the New Red or Permian Formations. In Table II., three are so supplied. In Table III., ten are so supplied.

From which it will be observed, that the largest number of towns supplied with New Red water are found in the tables with the lowest death-rate and the hardest water.

The same result is obtained if we compare towns of corresponding populations * and occupations supplied from surface areas with soft waters, and those supplied by deep wells in the New Red Sandstone. Thus: Manchester, with 351,189 inhabitants, has an average death-rate of 32·0 per 1000; while Birmingham, with 343,787, has only 24·4. And again Stirling, with 14,279 inhabitants, has an average death-rate of 26·1 per 1000; while Tranmere, with 16,143 inhabitants, has only 18·8.

But it may possibly be objected that the high death-rate

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* See Census of 1871.

of Manchester is not due to the softness of the water supplied to the inhabitants, but to the density of the population, the close proximity to the houses of cesspools and ashpits, and the want of care experienced by children in the manufacturing districts. And, again, that the low death-rate of Tranmere is due to the constant immigration of adults. And that these averages being dependent on so many external causes—not due to the purity or impurity, hardness or softness, of the water supply—is borne out by the facts that Greenock and Plymouth, both supplied with soft water, with an equal number of inhabitants, have a death-rate respectively of 32·6 and 23·3 per 1000, due to the difference of density of population, Greenock only having one house for every twenty-eight people. And, again, Liverpool and Birkenhead, both supplied with moderately hard water, the one an old and densely-populated town, with a site saturated with what is injurious to health, the death-rate is 34 per 1000; while Birkenhead, a new town on an open site with wide streets, has a death-rate of only 24 per 1000, though mainly inhabited by a poor and struggling class of persons.

But, at the same time, it is worthy of note, that the five inland manufacturing towns with the lowest death-rate are all supplied with hard water, and all from the New Red Sandstone.

	Population, 1871.	Mortality per 1000 per Annum.	Population, 1881.
Birmingham	343,787	24·4	400,757
Leicester	95,220	27·0	122,351
Nottingham	86,621	24·2	186,656
Stoke-on-Trent ..	130,575	27·9	152,457
Wolverhampton ..	68,291	25·9	75,738
Average ..	144,981	25·5	187,591

And again, the average death-rate of 12 inland non-manufacturing towns, supplied with soft water, was 26·0 per 1000, while that of 20 similar towns, supplied with hard

water, was only 23·2. When, however, the mortality of the district, including the principal English watering places, is compared, there appears to be little variation in the death-rate, whether the population be supplied with soft, moderately hard, or hard water; so that it may be safely concluded, that, where sanitary conditions prevail with equal uniformity, the rate of mortality is practically uninfluened by the degree of hardness of the water drank, and Her Majesty's Rivers Pollution Commission is of opinion that "soft and hard waters, if equally free from deleterious organic substances, are equally wholesome."

Jurassic Rocks.—Out of numerous samples of water from shallow wells in the *Lias*, analyzed by the Rivers Pollution Commission, from the Midland and Western Counties, only two were found to be fit for drinking and cooking—those of Somerby and Somerton. The total proportion of solid impurity rarely descends below 50 parts per 100,000, or 35 grains per gallon, and mounts up to 215 grains per gallon, the hardness being so great as to render them quite unfit for washing. These waters are also seriously polluted by the presence of animal organic matter, which largely escapes oxidation through the non-porous character of the Lias, the shallow wells in the more permeable New Red Sandstone being much freer from organic impurity.

Springs from the Lias form all or a portion of the water-supply of Cheltenham; Coaley, Gloucestershire; Grantham; Haydon, near Cheltenham; and Ilminster, Somerset. The waters are hard, though clear, colourless, and palatable, and much of the hardness is temporary. The total solid impurity is 36·41 parts per 100,000, or 25·49 grains per gallon.—The temperature of these springs ranges from 8°·2 C. to 15°·0 C.

The *Oolitic* rocks are very porous, absorbing and holding enormous volumes of water, which are again delivered as springs usually of great size. As water-bearing rocks are equal, if not superior, for the purification and storage of water, the oolitic rocks are equal, if not superior, to the chalk itself. But this vast store of magnificent water is rarely

SELECTED ANALYSES made for the RIVERS POLLUTION COMMISSION of WATER DERIVED from the OOLITIC ROCKS.

	Temperature. Centigrade.	Total Solid Impurity.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates or Nitrite.	Total Combined Nitrogen.	Previous Sewage Contamination.	Chlorine.	Hardness. Temporary.	Hardness. Permanent.	Hardness. Total.	Remarks.
SPRING WATERS.													
Bath, Hampton Down	8·1	22·40	·140	·007	0	·100	·107	680	1·30	15·1	3·5	18·6	Slightly turbid.
„ Egford Spring	10·0	30·76	·009	·004	0	·130	·134	980	1·46	21·8	5·4	27·2	
Yeovil (Somersetshire), water supply	8·5	24·76	·044	·077	·001	·300	·378	2,690	1·65	14·8	6·1	20·9	
Nunney, near Frome, proposed for water supply	..	31·10	·011	·099	0	·255	·260	2,230	1·26	19·1	6·0	25·1	
Chalford (Gloucestershire)	11·7	28·86	·083	·019	0	·285	·300	2,530	·97	20·9	3·6	24·5	
Gloucester, source of Arle Brook	11·8	44·52	·040	·010	0	·026	·036	0	1·60	18·4	13·5	31·9	
Longford (Gloucestershire) source of Avon	10·3	25·56	·053	·007	0	·398	·405	3,660	1·22	16·8	4·7	25·1	
Stroud (Gloucestershire), water supply from Gainer's Well ..	..	32·92	·014	·011	0	1·157	7·168	11,250	2·58	13·8	8·0	21·8	Clear and palatable.
Northampton, Garner's Spring ..	..	31·36	·009	·003	0	·790	·793	7,580	1·76	17·4	5·9	23·3	
Warkton, near Kettering (Northamptonshire), Cornwell's Spring	..	40·20	·071	·015	0	·682	·697	6,500	1·95	24·3	6·3	30·6	
THAMES BASIN. Bourton-on-the-Water, Eyeford Spring	10·0	26·86	·028	·004	·001	·290	·295	2,590	1·25	18·3	5·6	23·9	
Cirencester, Cowley Springs	10·0	24·32	·027	·005	·001	·232	·238	2,010	1·10	14·5	4·9	19·4	
„ the Seven Springs	10·2	22·60	·012	·009	·001	·510	·520	4,790	1·10	11·3	5·6	16·9	
„ Syreford Spring	10·0	22·34	·029	·008	0	·222	·230	1,900	1·20	13·8	5·1	18·9	
Daventry, source of Cherwell	9·0	27·30	·023	·009	0	·434	·443	4,020	1·70	16·7	5·7	22·4	
Donnington Mill, a source of the Windrush	10·0	27·48	·039	·017	0	·347	·364	3,150	1·40	17.3	6·6	23·9	Slightly turbid.
Seizincote, Pope's Hole, source of Evenlode	9·9	25·82	·047	·010	·001	·690	·701	6,590	2·20	12·0	7·1	19·1	Clear and palatable.
Starveall, spring above coppice	9·5	28·76	·034	·012	0	·590	·602	5,580	1·30	16·9	7·6	24·5	Clear and palatable.
Stow-on-the-Wold	9·9	24·44	·037	·010	0	·753	·763	7,210	1·40	14·3	6·3	20·6	

The Taddington, a source of the Windrush	11·8	31·20	·047	·014	0	0	·014	0	1·10	25·7	4·3	30·0	Traces of iron.
Scarborough, Old Waterworks Supply, Cayton Bay	10·0	30·38	·030	·007	0	·074	·081	420	3·30	13·5	8·3	21·8	Clear and palatable.
Average	..	30·33	..	..	..	..	..	..	1·55	18·2	6·2	24·4	
Deep Well Waters, Unpolluted.													
Stow-on-the-Wold (Gloucestershire), District Well, 120 ft. deep	..	32·30	·028	·009	0	1·898	1·907	18,660	3·20	8·3	10·6	18·9	Clear and palatable.
Cirencester, Thames Head Well, 60 ft.	10·5	27·44	·037	·018	0	·316	·334	2,840	1·35	18·0	5·0	23·0	Turbid, palatable.
Northampton, Berrywood Estate Well	..	26·60	·023	·005	·001	·374	·380	3,430	1·80	14·4	5·6	20·0	
Scarborough, Cayton new bore	12·0	41·90	·054	·011	0	·539	·550	5,070	3·40	12·1	9·1	21·2	Clear and palatable.
„ Grand Hotel bore, 214 ft.	12·2	39·78	·041	·008	·010	0	·009	590	3·70	16·1	3·6	19·7	
Average	..	33·60	..	..	..	..	..	..	2·69	13·8	6·8	20·6	
Shallow Well Waters.													
Bedford, Pillory pump	..	140·74	·325	·88	0	2·497	2·585	24,650	15·29	29·1	25·4	54·5	
Brackley (Northamptonshire) Howard's	..	84·88	·203	·085	0	4·432	4·517	44,000	7·90	10·8	33·5	44·3	
Warkton, Kettering Rectory ..	..	72·00	·266	·033	0	1·191	1·224	11,590	8·70	30·7	9·3	40·0	Clear and palatable.
Cirencester, Railway Station ..	..	59·20	·144	·019	0	·626	·645	5,940	2·80	32·4	5·5	37·9	
Frome (Somersetshire), Blue House Stone	..	86·30	·367	·064	·025	2·525	2·610	25,140	6·67	29·4	20·9	50·3	
Faringdon (Berks), Hinton Manor	..	101·50	·201	·066	·001	3·510	3·577	34,790	11·05	42·6	24·5	67·1	
Thame, Town pump	..	269·60	·759	·283	·006	12·220	12·508	121,930	44·50	23·0	55·9	78·9	Slightly turbid.
Witney (Oxfordshire)	..	145·00	·527	·250	·240	4·432	4·880	45,980	22·90	37·9	16·4	54·3	
Deep Well Waters, Polluted.													
Bourne (Lincolnshire), water supply	9·5	42·76	·217	·047	0	0	·047	0	2·10	23·4	11·8	35·2	
Witney, Clinch's Brewery, 65 ft. deep	10·3	71·04	·142	·053	·001	·308	·362	2,770	7·80	26·4	12·9	39·3	Clear and palatable.
Theescombe (Gloucestershire), 60 ft. deep	..	27·48	·106	·020	·002	·778	·800	7,480	2·50	12·6	8·6	21·2	

used by communities until it is hopelessly polluted. The analyses (see pages 42 and 43) show that great care should be exercised to cut off surface contamination in deep wells, and that shallow wells are absolutely unsafe. When care is taken to exclude sources of contamination, the water is remarkably free from organic impurity, the amount in some cases being as low as 0·047 part in 100,000, and 0·033 grain per gallon, at Scarborough well, and 0·02 part in 100,000, or 0·008 grain per gallon, in Garner's spring, Northampton. In fact, "unpolluted spring water from the Oolites is unsurpassed in its comparative freedom from all kinds of organic impurity."

An area of no less than 6671 square miles is occupied by the oolitic rocks of England, with an annual average absorption of not less than 8 inches of rainfall; a figure probably much below the real average.

These analyses show, in the words of the Commission, "that the oolitic rocks are not inferior to the New Red Sandstone, in the energy with which they oxidize and destroy the organic matter present in the waters percolating through them."

Though the waters so derived are generally hard, it is chiefly of a temporary character, capable of being softened by Clark's process, so as to average 6°·8 instead of 20°·6.

The oolites yield, in springs and deep wells, water which is "bright, sparkling, and palatable," and "excellent for drinking and all domestic purposes, except washing," for which the addition of lime renders it fit.

It is noticeable that the temporary hardness of the deep well waters is higher than that of the spring water, where care has been taken to exclude impurity.

Tunbridge Wells Sands, Lower Greensand and Upper Greensand.—The mean hardness of 19 samples from springs examined by the Commission was 20°·2, the hardest being the large spring flowing into the sea at Swanage (40°·2). Where these waters have not been in contact with calcareous strata they are soft; this is especially the case in the spring issuing from Mother Ludlam's (natural) Cave in the Lower

Greensand at Moor Park, near Farnham, the hardness of which was only 0°·7, which supplies Mr. J. F. Bateman's house.

Chalk.—This formation is an excellent filtering and cleansing material for water. Absorbing a larger volume than any other rock, it yields it up again, in deep-seated springs and wells, in a condition of freedom from organic impurity not surpassed by any formation. The unpolluted deep well waters are colourless, palatable, and brilliantly clear. The average hardness of the samples examined by the Commission was 27°·7, and after Clark's process 6°·5. The chalk constitutes an underground reservoir, in which large volumes of water are not only rendered pure, but stored and preserved at a uniform temperature of about 10° C. (50° F.), so as to be cool and refreshing in summer, and to be far from freezing in winter.

Temperature of Chalk Wells.*

Locality.	Depth.	Temperature. Centigrade Degrees.	Locality.	Depth.	Temperature. Centigrade Degrees.
Brighton	160	9·6	Amwell, N.R.C. ..	..	11·0
	100	10·0	Basingstoke	340	11·2
Bury St. Edmund's	..	5·0	Belvidere	70	11·5
Canterbury	..	10·8	Wheathamstead	175	10·3
Deal	115	11·3	Bushey Station	249	10·0
Dorchester	130	8·3	Caterham Works ..	490	11·2
Dover	220	11·3	Crayford, K. W. Co. .	200	11·4
	367	13·0	Croydon	..	13·5
Dunbridge, Hants	169	11·5	Deptford	250	12·2
Great Grimsby ..	300	11·5	Gravesend	200	9·7
Hull	..	11·5	Nettlebed	318	10·1
Ipswich	..	9·0	Plumstead	600	12·0
Ramsgate	100	10·0	Kidmore End, Reading	180	8·3

Tertiaries.—Next to the upland surface and spring waters from the Igneous and Silurian rocks, none analyzed by the Rivers Pollution Commission were so soft as those from the Lower London Tertiaries and the Bagshot beds, averaging

* Rivers Pollution Commission, 6th Report.

only 3·8; they were taken from the water supplied to Aldershot Camp, and from one of the affluents of the *Ravensbourne* at Keston, near Bromley, and the water supplied to Bournemouth; the latter had only 1·8 of hardness. None of the samples showed any traces of previous animal contamination, but all exhibited a large proportion of organic matter due to vegetable impurity.

Unpolluted water from deep wells in the Thanet Sands gave an average hardness of 22·0; the softest is from the Sheerness Dockyard wells. The old well is 450 feet deep, and the water is 16·7 C. when it is drawn up. The well at the waterworks is 384 feet, the temperature is the same, hardness 15·5. Chlorine in the old well 9·10, in the new 5·86. The London Clay is 330 feet thick, then light sandy loam, dark sand and clay, dark stiff clay to 400 feet, sand and clay, pebbles with water. Thirty tons of water are pumped per day of 7 hours. The hardness of the old well is 8·1; that of the waterworks contains less common salt, but is harder. Both wells send up water charged with sand and grit.

London; Edward Stanford, 55, Charing Cross, S.W.

Stanford Geog.l Estab.t

CHAPTER III.

RIVER BASINS OF THE NORTH-EAST OF ENGLAND (TEES, ESK, ETC.).

EXAMINING the watershed map in the Rivers Pollution Commission's 6th Report, it will be noticed that the great central watershed of England, separating the *SEVERN, DEE, MERSEY, RIBBLE,* and Lake District streams, from the *HUMBER,* the *TEES,* and the *TYNE,* is continued through Scotland to John o' Groat's, and hugs the western coast, running closely parallel to it, separates the Solway Firth, *CLYDE,* and West Highland streams from the basins of the *TWEED,* the *FORTH,* the *TAY,* the *DEE,* the *DON,* the *SPEY,* and the Lochs. It will be further noticed, that the strike of the ancient Palæozoic rocks of Scotland corresponds in direction with the Secondary rocks of South-eastern England, but the effect of the strike on the direction of the rivers is entirely different. In England the streams almost invariably cut across the strike, cutting deep gorges across escarpments of comparatively hard rocks, flowing generally down dip-slopes, and in some rare instances in a direction against the dip. This also is the case in the Carboniferous rocks of the *MERSEY, HUMBER,* and South Wales Coalfields, and the Devonian rocks of the South-west of England, and, to a certain extent, of the South of Ireland. In Scotland, north of the Carboniferous basins of the *CLYDE* and *FORTH,* the general direction of all the streams and lake-basins,* whether on the Atlantic or North Sea side of the great watershed, corresponds to the north-east and south-west strike of the rocks over which they flow. In the case of the chain of lakes connected by the Caledonian Canal, the gorges cut by streams flowing in

* The lake-basins represent the direction of the old ice-flow.

opposite directions coincide in position, and the watershed separating Eastern and Western Scotland descends to 94 feet above the sea.

The Commissioners divide Britain into five natural groups, draining in as many directions: 1. Eastern Britain, draining into the German Ocean, from John o' Groat's to the South Foreland, of which rather more than half the area is situated in England. 2. The South of England, draining into the English Channel. 3. The *SEVERN* and Bristol Channel streams. 4. West Wales and the English and Scotch streams, draining into the Irish Sea, embracing the country lying between St. David's Head and the Mull of Galloway. 5. The West Scottish streams, of which no portion occurs in the area described in this work.

Comparing the direction and position of the watersheds of South Britain with the geological structure of the country they traverse, it will be found that the influence of the tilt or dip given to the strata, and of anticlinal and synclinal curves in the structure of the rocks, produced by movements of subsidence and elevation, have in most cases been the governing influence which has determined the limits of the existing river-basins.

No division of basins into so-called natural groups can rest on a truly natural basis unless the key of geological structure is considered. This influence has been so all-important in giving what may be termed the *structure-lines* of the country, that the outline of its scenery and the shape of its contours are as strictly dependent upon it, as is the shape of the human figure on the bones and muscles that make up its structure.

The boundary line between England and Scotland is essentially artificial. West of the great watershed parting, the *ESK* falls into the Solway Firth on the English side of the Border, after draining with its tributaries a large area in Scotland; while, east of the great watershed, the river *Till* discharges the drainage of an English area into the *TWEED*, of which it is a tributary, on the Scotch side of the

Border. The more natural division would have been to have thrown the whole of the Commissioners' 4th Group into England, the boundary of which would have followed the watershed from Port Patrick by the Lead Hills, and thence, crossing the central watershed north of Moffat and near the head waters of the *CLYDE*, the *ANNAN*, and the *TWEED* (at an elevation of 1500 feet), would have passed eastwards, and formed the southern margin of the basin of the *TWEED*.

The existing boundary is formed by the *TWEED* watershed, for about eighteen miles, commencing where the watershed ceases to divide the *TWEED* from the Solway Basin streams, and separates the *TWEED* from the *TYNE*, *COQUET*, and *ALYN*. The country boundary leaves the *COQUET* basin where the latter abuts against the *Till*, and thence it runs across the *Till* basin to the River *TWEED*, and follows the channel of that river to the sea at Berwick-on-Tweed.

The *TWEED* occupies an area in England, according to the Ordnance Survey Catchment Basin Map, of 37 square miles, which are entirely situated on Carboniferous rocks, 3 square miles consisting of Mountain Limestone, and the remainder is also partially permeable. Professor Lebour, in a paper 'On the larger Divisions of the Carboniferous System in Northumberland,' states from the unconformity of the Permian friable Yellow Sandstone, the true highest bed of the Coal Measures is not known; they were estimated by Mr. George Tate at 2000 feet, which probably included the Gannister Beds, the hard fine-grained sandstones underlying the lowest workable seams of coal. The Millstone Grits in Northumberland are seldom coarser than the Sandstones of the Coal Measures, and are neither so thick nor so coarse as the Grits in the limestones beneath. In fact this horizon is largely characterized by shaley sandstones, shales and sandy shales, and Professor Lebour groups them with the Gannister Beds, forming the base of the Coal Measures. Beneath them is the Bernician Series, heralded in by the first Calcareous

band, the Fell-top Limestone. In this series Professor Lebour unites the so-called Yoredale Series with the Scar Limestones. Beneath this series Professor Lebour unites the Calciferous Sandstone with the so-called Upper Old Red Conglomerates of the flanks of the Cheviots under the name of the Tuedian Series.

The chief places in this area are Norham, Spittal, Ancroft, and BERWICK-ON-TWEED, which covers 6320 acres, with 8718 inhabitants. Supply from (*a*) a spring in the Mountain Limestone at Tweedmouth, pumped unfiltered to the high service reservoir, containing 255,062 gallons; it is partly above ground and partly below, and is covered. The quantity used from this source is 194,000 gallons. The Rivers Pollution Commission states that the water is well adapted for domestic use, and has a hardness of only 11·4, while the water supplied to the town from other sources was 19·5; (*b*) a collection of springs and land drains called the Wine Wells Eyes Supply, running by gravitation into the same reservoir; the Rivers Pollution Commission states these might be retained, though not equal in quality to the Tweedmouth spring; (*c*) a gathering ground of 338 acres, with storage reservoir of 5 acres, holding 8,500,000 gallons, at New East Farm, 3 miles from Berwick, from which the water runs by gravitation into the same reservoir as source (*a*), but the quality of the water is bad, and it is only used as a reserve. The total supply is 300,000 gallons per day, and is constant for nine months in the year. Rateable value, 39,225*l*. Works carried out under Public Health Act and 26 & 27 Vict. c. 32.

The tributaries to the *TWEED* in England are the *Till* (II.) 38 miles in length, and the *Glen*, 10 miles, occupying 231 square miles, all of which consist of Carboniferous rocks, 23 belonging to the Limestone series. The rainfall is 26·6.

The chief towns and villages are Coldstream, Crookham, Wooler, 158 feet above the sea, and Chillingham, 181 feet.

ORDNANCE SURVEY BASIN III.

These streams occupy 129 square miles. The *ALYN* Basin (IV.) occupies 104 square miles, and is 18 miles in length; it consists entirely of Carboniferous rocks, comprising, with Basin III., 40 square miles of the Limestone series and 193 of higher Carboniferous. The rainfall is 24·2 in Basin III., and 27·8 in the *ALYN* Basin.

The chief places in Basin III. are Holy Island, Lowick, Belford, Embleton; the highest point of the watershed is 407 feet. In Basin IV. the chief places are Lesbury and Alnwick, 105 feet above the sea; Eglenham, Whittingham; highest point of watershed about 800 feet. Rainfall at Alnwick Castle in 1879, 33·36.

Alnwick and Canongate, Urban Sanitary District, contains 4778 acres, with 6691 inhabitants. The average daily water supply of 150,000 gallons is constant from a gravitation tank and filter bed, storing springs 2 to 3 miles distant, and in dry weather a brook is also taken in. Rateable value 19,408*l*. Works carried out under Public Health Act, 1848.

RIVER COQUET (V.)

This river has a length of 40 miles; area 240 square miles, of which 24 are in Carboniferous Limestone series, and the remaining 216 square miles other Carboniferous rocks. The base of the Bernician Series in the Upper *COQUET* consists of the Harbottle Grits, and in the burn valleys running north into the Upper Redewater of the Great Dour Grits resting on the Tuedian purple shales and cream-coloured beds. Mr. Topley of the Geological Survey points out that the distribution of upland peat-bogs, which act as natural compensating reservoirs, gradually parting with their water, has been an active cause of floods in the lowlands, these sometimes rising 20 feet. Average rainfall is 33·7.

Chief places are Felton, Rothbury, 265 feet; Alwinton, 498 feet. Highest point of watershed about 419 feet.

O.S. CATCHMENT BASIN X.

These streams occupy 18 square miles of Carboniferous rocks, of which 1 is in the Limestone series.

O.S. CATCHMENT BASIN XI.

This basin occupies 37 square miles of Carboniferous rocks, of which 4 are Limestone. The chief places, Newbiggin (Urban Sanitary District, 300 *acres*, 1410 population, supplied by spring, wells, and pumps. Rateable value, 3897*l.*). Woodhorn, 33 feet; Ulgham. Highest point of watershed, 523 feet.

RIVER WANSBECK (IX.).

The length of this river is 22 miles, with a tributary, the *Font*, 12 miles long. Area, 126 square miles of Carboniferous rocks, of which 12 are Limestone. Rainfall, 29·0 inches. Chief places, Bothal, 28 feet, Morpeth, Mitford, Hartburn. Highest point of watershed, 1050 feet. Urban Sanitary Authorities:—

Cowpen.—*Acres*, 438; population, 5065; supply 80,000 to 187,000 gallons from covered reservoir, collecting springs at Healey Wood, Clyton, and Hepscott, on estate of the Earl of Carlisle. Rateable value, 11,835*l.* 18*s.* 4*d.* Local Government Act, 1875, 38 & 39 Vict. c. 175.

Cramlington.—*Acres*, 3582; population, 5746; supply 99,000 from 16 wells, and 111,380 gallons pumped from two coalpit shafts into reservoir. Rateable value, 18,414*l.*

Morpeth.—Population, 6115; supply 100,000 gallons, from land drainage, rivulets, and springs, collected in a storage reservoir, flowing by gravitation into a service reservoir. Rateable value, 19,744*l.* Rainfall 29·65 in 1879.

RIVER BLYTH (XII.).

The length of this river is 16 miles; area, 131 square miles, including the country drained by the *Pont*, 16 miles

n length; 12 square miles are Carboniferous Limestone, and 114 higher Carboniferous beds. Rainfall is 25·5. The chief places, Stannington, 97 feet above the sea; Ponteland, 190 feet; and the following Urban Sanitary Authorities:—

Bedlingtonshire.—Population, 14,527; supply 150,000 to 200,000 gallons, pumped from *BLYTH* by steam power. Rateable value, 39,225*l.* 12*s.* Bedlington Water (Local Board) Act, 1878, gives power to pump up to 400,000 gallons. South Blyth, *acres*, 38. Population, 1982; supply 70,000 gallons from private works of Sir M. W. Ridley, Bart. Rateable value, 5917*l.* Highest point of watershed, 758 feet.

O.S. CATCHMENT BASIN XIII.

This basin occupies 31 square miles of Carboniferous rocks, of which 3 are Limestone. Rainfall, 23·4. Chief places, Seaton Sluice, Earsdon. Highest point of watershed, about 232 feet.

RIVER TYNE (VIII.).

This river and its tributaries occupy an area of 1130 square miles, entirely consisting of Carboniferous rocks: 113 square miles are occupied by Carboniferous Limestone. Its length is 34 miles, that of the *North Tyne* being 39 miles, the *South Tyne* 38, the *Rede* 22, the *Alyn* 13, the *Derwent* 30. Chief towns, Tynemouth, South Shields, Newcastle, 33 feet, and Hexham.

Newcastle and Gateshead Waterworks Company.—In 1868 Mr. John Taylor reported to the Royal Rivers Commission that the population was 200,000, and the quantity of water supplied 5½ millions of gallons per day, or 27½ gallons per head per day. The original gravitation works constructed in 1846–8 at Whittle Dean were designed for the supply of 3¼ million gallons per day, from a gathering-ground of 4340 acres, with reservoir capacity of 215 million gallons, or only 7900 cubic feet per acre. The quantity then used was about 1½ million gallons per day, so that the reservoir held 143

days' supply at that quantity, or for 66 days, at the maximum quantity. The supply was introduced in 1848, and failed in 1850, when the River *TYNE* had again to be pumped. Additional storage reservoirs were constructed, but these also failed to give sufficient supply in dry years. The latest and largest store reservoir was finished in the spring of 1857, and the storage was then 500 million gallons, or 90 days' supply. The rainfall at Whittle Dean that year was only 22 inches, and an eight-months' drought commenced in December, lasting up to May, 1858, during which only 3 inches of rain fell. The increased store was exhausted early in 1857, and not replenished that winter, so that in 1858 recourse to the *TYNE* had again to be effected. In 1860 the gathering-ground was increased to 17,300 acres, extending from Harlow Hill to Thockrington, or a storage capacity of 4900 cubic feet per acre, less than was originally designed. The estimated yield has never been realized; the average rainfall was assumed to be 24 inches, and half was considered available, but though the average of the eighteen years ending 1867–8 gives 24 inches, the yield in years of drought has only amounted to little more than 6 inches, or only one-fourth the average, and half the anticipated quantity. The Company, to remedy this, erected a permanent pumping station to pump the *TYNE* at Newburn to the extent of 5 million gallons a day.

Rainfall Observations taken by Mr. D. D. Main, at Newcastle and Gateshead Waterworks.

	Feet above the Sea.	Inches, 1879.	Inches, 1880.
Whittle Dean	..	25·26	29·21
Swinburn (Woodford) ..	500	29·53	29·37
North Tyne (Green Crag)	800	32·42	30·06
„ „ (Valley) ..	300	27·67	29·64
Hallington	469	31·54	31·89
„ (Fawcett) ..	563	28·52	29·26
Gunnerton Burns	676	29·00	28·68

The Rivers Pollution Commission states that of the 17,000 acres of gathering-ground, one-fourth of the land is arable,

receiving periodical dressings of farm-yard manure, and three-fourths is pasture. The water is continually flowing by gravitation into subsiding reservoirs, and thence into 9 impounding storage reservoirs, from which it passes outwards through screens of copper gauze (48 strands per inch) into the mains. There are three filter-beds, with a filtering medium of broken freestone, rough and fine gravel, and sand 3 feet and a half deep, but these are only used when the *TYNE* water is pumped direct, which is only in extreme drought. The Company's system extends over no less than 95 square miles, which necessitates pumping stations at several points to obtain the necessary head: the annual cost of pumping is 3884*l*. The total solid impurity was 23·40, hardness 13·9, of which 8·1 was permanent. The water contains 0·237 of organic carbon, which is just above the limit (0·200) the Rivers Pollution Commission considers prejudicial to health. By long storage all traces of previous animal contamination has been removed. The Chlorine is 1·59. The total reservoir storage is 1,200,000,000 gallons, and they have recently commenced the construction of another reservoir, to hold 900,000,000 gallons. Their works are carried out under Acts of 1863, 1866, 1870.

They supply:—Newcastle-upon-Tyne, *acres*, 5326; population, 145,228; supply, 9,000,000 gallons; rateable value, 701,613*l*. Gateshead, *acres*, 3135; population, 65,873; supply, 1,800,000 gallons; rateable value, 196,790*l*. Felling, *acres*, 2702; population, 17,137; rateable value, 48,048*l*. Walker, *acres*, 1200; population, 9522; rateable value, 34,000*l*. Wallsend, *acres*, 1097; population, 6515; rateable value, 28,576*l*. 2*s*. 4*d*. Willington Quay, population, 5105; rateable value, 18,661*l*. South Gosforth, *acres*, 1298; population, 4125; rateable value, 19,144*l*.

Blaydon-on-Tyne.—*Acres*, 9347; population, 10,689; supply of 45,000 to 85,000 gallons, from a reservoir; rateable value, 37,868*l*.; Public Health Act, 1870.

Whitby and Monkseaton.—*Acres*, 1800; population, 1200; supply, 7200 gallons from North Shields Water Com-

pany in Whitby, public pumps in Monkseaton; rateable value, 13,681*l.*

Howden-on-Tyne.—Population, 1099; constant supply, spring well and Whittle Dean Water Company; rateable value, 2227*l.*

Seghill.—*Acres*, 1415; population, 2134; constant supply from reservoir for washing purposes, wells for drinking; rateable value, 10,227*l.* 6*s.* 8*d.*; Public Health Act, 1875.

Hexham.—Population, 5919; supply of 112,000 gallons from a reservoir storing natural drainage area of 220 acres; extended scheme for taking 1300 acres is approved by Local Government Board; rateable value, 19,238*l.*

Tynemouth.—*Acres*, 4303; population, 43,863; supply from (*a*) springs in Magnesian Limestone, from (*b*) shaft in Coal Measures, (*c*) gravitation catchment works—in all, 520,000 gallons; Company under 26 Geo. III. c. 110; Local Board wish to purchase works.

Alston.—Rainfall in 1879, at 1145 feet above the sea, 36·35 inches.

RIVER WEAR (*XX.*).

This river is 65 miles long, with an area of 456 square miles, of which 45 consist of the Carboniferous Limestone series, and 411 of higher Carboniferous rocks. The rainfall is 24·2.

The chief Urban Sanitary Districts are as follows:—Supplied by the *Sunderland and South Shields Water Company*, who deliver daily 4,500,000 of gallons of water, to the boroughs of Sunderland and South Shields, and to the Local Board of Jarrow, Hibburn, and other villages. The supply is derived from deep wells sunk into the Magnesian Limestone, stored in 10 reservoirs, and the works are carried out under the Sunderland and South Shields Waterworks Act, 1852, amended by Acts of 1859 and 1868. Rainfall at Sunderland in 1879, 132 feet above the sea, 26·58.

Statistics of Urban Sanitary Districts supplied:—SUNDERLAND, population, 116,262; rateable value, 349,500*l.* South Shields, *acres*, 1760; population, 56,922; rateable value, 154,254*l.* 10*s.* Jarrow, *acres* 851; population, 25,531; rateable value, 57,960*l.* Southwick, *acres*, 856; population, 8207; rateable value, 18,477*l.* 11*s.* 6*d.* Dawdon, *acres*, 1088; population, 7638; 72,000 gallons, constant; rateable value, 20,667*l.*

Supplied by the *Weardale and Shildon District Water Company*, who give a constant supply of filtered water from a reservoir, under 29 & 30 Vict. c. 300, and 38 & 39 Vict. c. 221: Shildon and East Thickley, *acres*, 1065; population, 8704; 280,000 gallons; rateable value, 25,696*l.* Spennymoor, population, 5917; rateable value, 12,600*l.* Tow Law, *acres*, 468; population, 7900; rateable value, 12,500*l.* Brandon and Byshottles, *acres*, 6683; population, 10,850; rateable value, 40,834*l.* 3*s.* 9*d.*

Supplied by the *Consett Water Co.*, who give a constant supply from a reservoir, but the water requires filtering:—Consett, *acres*, 1024; population, 7162; rateable value, 21,322*l.* 15*s.* Benfieldside, *acres*, 1630; population, 5695; rateable value, 14,497*l.* Leadgate, *acres*, 1304; population, 4279; rateable value, 11,759*l.*

The city of DURHAM is supplied by a company incorporated under the Joint Stock Companies Act. The supply is constant, pumped from the River *WEAR* and filtered, averaging half a million gallons daily. The population is 14,932, and rateable value 46,474*l.* 10*s.*

Other Local Authorities:—

HOUGHTON-LE-SPRING.—*Acres*, 1285; population, 6041; supply, water pumped from a shaft at Houghton-le-Spring, by the Earl of Durham, for the sum of 300*l.* per annum; a reservoir belonging to the Local Board; constant supply; 65,000 gallons used, and a further 15,000 gallons by manufacture; in all 80,000; rateable value, 17,997*l.*; Public Health Act, 1848.

BISHOP AUCKLAND.—*Acres*, 950; population, 10,087;

supply, pumped from gravel bed in River *WEAR*, in which the water filters naturally; a service reservoir at highest point of district E.; constant 250,000 gallons; rateable value, 31,790*l.* 6*s.*; Public Health Act, 1848.

STANHOPE.—*Acres*, 234; population, 1840; supply, spring 2 miles distant; reservoir; constant 200,000 gallons; rateable value, 3200*l*; Sanitary Acts.

Chester-le-Street is 43 feet above the sea; Durham, 130 feet; Bishop Auckland, 258 feet; Walsingham, 471 feet; Wearhead, 1193 feet; and the highest point of the watershed, 2326 feet.

Durham Type of Permian Rocks.

In Durham and the north-east of England the sequence is widely different to the Midlands. That at Durham is described by Prof. Lebour as follows:—

5. Magnesian limestone. Crystalline Concretionary.
4. Marl slate.
3. Magnesian limestone in inconstant beds.
2. Yellow sands.
1. Red Sandstone (stained Coal Measures).

The basement Yellow Sands lie irregularly and unconformably on the so-called Lower Red Sandstone of the Coal Measures in hollows eroded in its surface. Large quantities of water are pumped from these sandstones, and from the Magnesian Limestone of this county, for the supply of Sunderland, South Shields, Jarrow, Seaham, and several villages—the quantity pumped from an area of 50 square miles overlying the Coal Measures being, according to Messrs. Daglish and Forster, no less than 5,000,000 gallons per day, which abstraction has not in the least altered or lowered the permanent water-level in the rock of this district, which occurs along the coast at mean-tide level, rising to 180 feet above it inland.

The following analysis of the Sunderland water is given by the Rivers Pollution Commission:—

Total solid impurity		44·18
Organic Carbon		·035
Organic Nitrogen		·030
Ammonia		0·0
Nitrogen as nitrate and nitrites		·416
Nitrogen, total combined		·446
Previous sewage contamination		3·840
Chlorine		4·17
Hardness	Temporary	·8
	Permanent	13·9
	Total	14·7

The Commissioners comment on the fact that magnesian spring water, at Waterham's Field, Pontefract, is not only excessively hard, but differs from the Sunderland well-water in having a large amount of temporary hardness (24·9); but it is important to notice that the water of Sunderland, unlike that of Pontefract, is obtained from the Sandstone beneath the Magnesian Limestone, and not from the Dolomite itself.

These limestones, as stated by the Commissioners, are rarely used as a source of water-supply; Dolomite, being a double carbonate of lime and magnesia, imparts both these substances to the water. 100,000 lbs. of the Sunderland water contained 5·89 lbs. of lime and 3·96 lbs. of magnesia, which must be due to the percolation of the water through the porous limestone before it reached the underlying sandstone.

These limestones of Durham gradually thin away to the south, through Yorkshire and Derbyshire, and die out near Nottingham. The thin limestones of Lancashire, hereafter described, may be considered their debased and argillaceous equivalents, the fossils occurring at Astley and Bedford Leigh being the well-known Magnesian Limestone genera *Tragos, Schizodus, Bakevellia,* and *Turbo.*

The less crystalline limestones hold 3·45, 6·0, 13·13, 14·87, and even 17·0 lbs. of water to the cubic foot. The Sandstones vary less, 10 lbs. of water (a gallon) being the average point of saturation. The more crystalline limestones absorb very little.

O.S. CATCHMENT BASIN XXI.

These streams occupy 17 square miles, wholly in the Magnesian Limestone.

The Hartlepool Gas and Waterworks supply the following districts under their Gas and Water Act, and under the West Hartlepool Extension and Improvement Act, 1870, section 51 of which, like section 62 of the Public Health Act, 1875, ordains that good water should be supplied. The supply is constant, derived from four artesian wells, and stored in reservoirs.

HARTLEPOOL.—*Acres*, 136; population, 12,684; supply, 20 gallons per head, and about 263,000 gallons daily, for domestic use only; rateable value, 25,837*l.* Rainfall at Hart Reservoir in 1879, at 164 feet above the sea, 21·71.

WEST HARTLEPOOL.—*Acres*, 1280; population, 28,167; supply, Company and numerous private wells; rateable value, 98,153*l.*

THROSTON.—Population 3472; rateable value, 10,000*l.*

MIDDLETON-IN-STRANTON.—Population 1216; rateable value, 5005*l.*

SEATON-CAREW.—Population 935; rateable value, 3300*l.*

The highest point of the watershed is about 576 feet above the sea.

RIVER TEES (XXII.).

The length of this river is 79 miles, of its tributary, the *Skerne*, 22 miles, of the *Leven* 14 miles; area, including tributaries, 708 square miles, of which the Carboniferous Limestone series occupies 66 square miles, Carboniferous rocks, 264, Magnesian Limestone, 130, Triassic rocks, 130, and Liassic 78. Rainfall is 17·3 to 20·6. Stockton-on-Tees is 34 feet above the sea; Barnard Castle, 464 feet; and the highest point of the watershed, 2930 feet.

In the Cross Fell and Alston Moor district the Mountain Limestone is split up into numerous beds of Limestone, Sandstone, and Shale, the thickness and character of which are well known through the local names given to each horizon by

the miner, and from the writings of Messrs. Westgarth Forster, Sopwith, and Wallace. The chief beds of Limestone above the Whin Sill, a sheet of probably intrusive basalt, are the Little Limestone (20 feet below which are two thin coal seams); the Tumblers, or Great Limestone, about 70 feet thick; the Scar Limestone, about 30 feet; and the Cockle-shell, full of *Productus;* the Tyne-bottom Limestone, about 24 feet, resting on the Tyne-bottom Plate (=Shale), resting on the Whin Sill. The Shale is about 50 feet, and the Whin about 110 feet, often much less. Below it are 900 feet of measures, the chief Limestones being the Jew, and the Melmerby Scar, 124 feet thick.

Stockton and Middlesborough Waterworks Company obtain their supply from the *TEES*, which they filter. They supply:—STOCKTON (*Durham*), population, 41,040; rateable value, 114,484*l.* South Stockton, *acres*, 1052; population, 10,590; rateable value, 36,840*l.* MIDDLESBOROUGH (*Yorkshire, North Riding*), population, 55,288; rateable value, 202,127*l.* Normanby, *acres*, 1462; population, 7689. Ormesby, *acres*, 4463; population, 7761. Kirkleatham, *acres*, 4330; population, 3898; rateable value, 27,476*l.* The works were carried out under Stockton and Middlesborough Waterworks Company's Act; their undertaking was purchased by the Stockton and Middlesborough Corporations, by an Act obtained in 1876.

The *TEES*, filtered, also supplies DARLINGTON, *acres*, 3899; population 35,102; supply 1,200,000 gallons; rateable value, 159,922*l.*; works purchased by Local Authority, 1854. BARNARD CASTLE, *acres*, 682; population, 4544; supply from reservoir storing springs, yielding 120,000 gallons a day; rateable value, 11,000*l.*; Public Health Act.

In the *TYNE* and *TEES* basin, 170 square miles of Triassic rocks occur, about 100 miles being sandstone, and the remainder marl. The ground is low, and the permian limestone, with thick salt beds, occur below, and no good supply of triassic water can be relied on. Through the kindness of Mr. E. Best, of H.M. Geological Survey, I have been able

to examine the 6-inch maps of the district around Middlesborough, in Durham and Yorkshire, surveyed by Mr. H. H. Howell, on which the positions of the various deep borings are marked, as well as the natural exposures of rock. At Hunworth, and near Low Diresdale, current bedded red and yellow flaggy sandstone at 10° to the northward. This dip is, however, probably local, as further eastward good sections of these sandstones occur in the banks of the River *TEES*, in the direction of Stockton, dipping S.E., which is also the dip of the Magnesian Limestone of Aycliffe, and that of the overlying Rhætic beds of Yorkshire. This dip evidently obtains in the Middlesborough salt area, as the salt deposit was met with at a shallower level at Messrs. Bells' boring, north of that of Messrs. Bolckow and Vaughan's. Still further north there is a local roll on the coast near Greatham, close to which there is a boring, 1½ mile W. of Seaton-Carew, 529 feet deep.

The following is an abstract of the section passed through by the Diamond Drill Company on Salthouse Farm on the Durham side of the *TEES*, for Messrs. Bell Brothers, 15th December, 1874, kindly communicated to me by Mr. Allison, of Guisborough :—

	Feet	in.
Drift Sand and Boulder Clay	77	0
Red Sandstone, with bands of Marl, chiefly blue	778	0
Stony Marl	20	0
Red Marl and Sand	5	0
Red Sandstone and Marl	14	0
Strong Marl, bands of Sandstone	6	0
Strong Marl	23	0
Strong Marl and Gypsum	7	0
Marly Sandstone and Gypsum	197	7
Rock Salt (top 1127·7 from the surface)	75	5
Shale, Gypsum, and Salts	58	0
Magnesian Limestone	67	0
Gypsum	9	0
Rock Salt	14	0
Marl, Salt, and Gypsum	3	0
Rock Salt	1	0
	1355	0

In the boring by Messrs. Mather and Platt's process at Middlesborough, for Messrs. Bolckow, Vaughan, and Co., begun 4th July, 1859, finished 29th August, 1863, of which a section has been published by Mr. John Marley, C.E.* The glacial drift was 58 feet thick. Gypsum first appeared at only 76 feet from the surface, at 178 feet a bed of Red and White Sandstone with water came in (Waterstones?) followed by Sandstone and blue clays (Permian?), Gypsum reappeared at 1059 feet, 2 feet 8 inches of Limestone at 1191·10, 88 feet 5 inches of salt rock at 1206 feet from the surface, 1 foot of Limestone at 1307 feet, and 6 feet 4 inches of "Conglomerate" down to 1313·4, at which depth the boring ceased.

O.S. CATCHMENT BASIN XXIII.

These streams drain 100 square miles. The rainfall is 18·0. The chief places, Marsk, Skelton, Guisborough, Hinderwell. The highest point of the watershed is about 712 feet.

RIVER ESK (XXIV.).

This river is 21 miles long, and occupies 147 square miles of this area, together with the 100 square miles in Basin XXIII.; 64 square miles consist of Lias, and 183 of Oolites. The rainfall is 28·2. The chief places, Whitby, Egton, 138 feet; Castleton. The highest point of the watershed is 1398 feet.

Whitby, North Riding.—*Acres*, 2009; population, 14,014; springs, a service reservoir, 300,000 gallons; rateable value, 33,359*l.*; the Whitby Waterworks Act, 1874. Rainfall in 1879, at 184 feet, 21·96.

Guisbrough. — *Acres*, 6120; population, 6616; springs on moors, and in summer and autumn reservoirs; about 95,750 gallons; rateable value, 32,000*l.*; Provisional Order of the Board of Trade, intituled "The Guisbrough Water Order, 1871." Rainfall at Hutton Hall, 400 feet above the

* Report, British Association, 1863.

sea, in 1879, 27·22. At Lockwood Beck reservoir, 632 feet above Ordnance Datum, it was 28·45.

Loftus.—*Acres*, 2648; population, 8620 (estimated); the Cleveland Water Company reservoirs belonging to Earl Zetland; pumps, deep wells, and public fountains; rateable value, about 34,000*l.*

Redcar.—Population, in 1881, 2458; spring, and is of excellent quality, reservoir; 25 gallons per head (c.): rateable value, 10,762*l.*; the Local Government Acts.

Skelton-in-Cleveland.—*Acres*, 3830; population, 9374; part supplied direct from springs in freestone rock, and the remainder from filter beds in connection with storage reservoir on moorland (c.); rateable value, 45,657*l.*; Cleveland Waterworks Acts, 1869, 1871, and 1876.

Population in North-Eastern Group of River-Basins.

County.	Population (County).	Density. Acres to Person.	Proportion of Population in this Group.	Probable Population.
In Census 1871.				
Northumberland	386,759	3·2	All	386,759
Cumberland	220,245	4·5	$\frac{1}{22}$	10,000
Durham	685,045	0·9	All	685,045
Yorkshire, N.R.	291,589	4·0	$\frac{1}{10}$	29,158
In Census 1881.				
Northumberland	434,024	2·9	All	434,024
Cumberland ..	250,630	3·8	$\frac{1}{22}$	11,392
Durham	867,586	0·7	All	867,586
Yorkshire, N.R.	316,147	3·9	$\frac{1}{10}$	31,614

CHAPTER IV.

BASIN OF THE HUMBER.

The tides of the *HUMBER* are stormy, and carry much silt, which is deposited capriciously when the tidal stream is diverted from any spot; the whole of its area is tidal; it receives the drainage of at least a dozen river-basins, occupying no less than 10,500 square miles, or one-fifth of England and Wales. Mr. Shelford, C.E., has pointed out * that the tidal capacity of the rivers on the English coasts are always sufficient to store any floods that may come down from the uplands; thus a flood caused by the fall of a rainfall of $\frac{1}{2}$ inch over the entire *HUMBER* basin, would be only equal to one-fourth of the tidal capacity of that river, which is no less than 1770 million cubic yards. The original estuary water space was 400 square miles, which has been reduced to 110 square miles by reclamation, according to Mr. Bateman, but the river has maintained its depth, and improved its channels.

Examining a map of the course of the rivers, it will be noted that a line continuing the trend of the *HUMBER* westward from Kingston-on-Hull, through the outfall of the *AIRE*, passes along the course of the Yorkshire *Calder*, and then, crossing the Pennine Chain, near Todmorden, traverses Lancashire, and intersecting the estuary of the *RIBBLE*, reaches the Irish Sea. The *Calder*, therefore, with the *AIRE*, may be taken as the central element of the *HUMBER* group of river-basins. *North* of it is the Yorkshire *OUSE*, with its tributaries the *Wharfe*, *Nidd*, *Ure*, and *Swale*. *South* of it is the *DON* and the *TRENT*, with the

* 'Min. Proc. Inst. C.E.,' vol. xxviii. p. 472.

important tributaries of the latter, the Derbyshire *Derwent*, and the *Soar*. The drainage of these five basins falls into the central stream, within the space of 15 miles, at levels of only 7 to 18 feet above the mean level of the sea. *East* of the *TRENT*, the River *Ancholme* and other streams draining into the Estuary of the HUMBER, form a South-eastern group.

North-eastern Group.—Sea-coast from Robin Hood's Bay to Spurn Head, and mouth of the Humber, left bank :—

O.S. CATCHMENT BASIN XXXVII.

These streams occupy 157 square miles. Chief towns, Scarborough, Filey, Hunmanby, Bridlington, Hornsea. Of this area 57 square miles are Oolites, 12 Greensands, and 88 Chalk.

HORNSEA. — *Acres*, 3000 ; population, 1836; private pumps, and two public pumps in the streets; Local Board Waterworks, constructing, boring, and tower; 20 gallons per head ; rateable value, 11,270*l.*

BRIDLINGTON. — *Acres*, 2500 ; population, 8363; from two wells 150 feet deep, reservoir, 150,000 gallons (c.); rateable value, 26,552*l.* 15*s.*

FILEY.—*Acres*, 652; population, 2337; springs, reservoir (c); rateable value, 926*l.*; Filey Water and Gas Company Act.

SCARBOROUGH.—*Acres*, 2292; population, 30,484 ; from springs at the foot of the cliff in Cayton Bay, and from a well at Cayton, both about 3¾ miles south of Scarborough ; by reservoir, to which the water is raised by pumping; maximum quantity used daily, between 800,000 and 900,000 gallons (c); rateable value, 135,695*l.* 11*s.*; 8 & 9 Vict. c. 68 (1845), the Scarborough Waterworks Amendment Acts (1856, 1863); the Corporation of Scarborough has purchased the undertaking under an Act, powers were given for the

transfer on the 1st October, 1878. Rainfall at Osgodby in 1879, at 262 feet above the sea, 28·31 inches.

Mr. Fox-Strangways, of the Geological Survey, considers the waterworks well between Osgodby and Cayton penetrates the whole of the Coralline Oolite and Calcareous Grit; drift was 31 feet 9 inches; limestone bands, 103 feet 3 inches; and shale, 6 inches. At the borehole at the New Laundry, near Scamer Lane, drift was 90 feet thick, and the Upper and Middle Estuarine (oolite) deposits, 222 feet, consisting of alternate bands of sandstone and clay, two beds of the former being 40 feet and 55 feet.

Mr. Fox-Strangways, in his description of the country around Scarborough and Filey,* remarks on the fact that nearly the whole area is drained by the *Derwent;* this river, in preference to taking the apparently direct and open valleys to the east, has cut its way southwards through two oolitic barriers, the first of them forming the picturesque gorge of the Forge Valley. He remarks on the influence that the geological structure has had in the selection of sites for villages, nearly all being "on either edge of the great clay valley, where springs of beautiful calcareous water burst out; on the north, at Witton, Allerston, Ebberston, Snainton, Brompton, Wykeham, Hutton Buschel, Ayton, and Seamer; south are Rillington, Thorpe Basset, Wintringham, Heslerton, Sherburn, Ganton, Flexton, Folkton, Hunmanby, and several smaller hamlets."

The Lower Oolite consists of—

Cornbrash, *Avicula echinata:* grey rubbly iron-shot Limestone, a few feet thick.

Inferior Oolites.
- Upper Estuarine Series: Current-bedded Sandstones, 220 feet.
- Scarborough, or Grey Limestone Series: Calcareous Shale, 70 feet, at Cloughton Wyke.
- Middle Estuarine Series: Shale, Sandstones, and streaks of Coal.
- Millepore Series: Calcareous Sandstones, with ferruginous partings.
- Lower Estuarine Series: Carnelian Bay, massive Sandstones.

* Memoirs of the Geological Survey. 'The Geology of the Country around Scarborough and Filey.' 1880.

The Middle Oolite consists of—

Upper Calcareous Grit (uncertain).
Upper Limestone (coral rag), 90 to 100 feet.
Middle Calcareous Grit: Silicious cold land, with "swallow holes."
Lower Limestone: 30 feet at Scarborough Castle Hill.
Greystone and Passage Beds: Hard silicious current-bedded, 25·30 feet.
Lower Calcareous Grit: Massive yellow calcareous Sandstone, 100 feet.
Oxford Clay: Grey sandy Shale, 120–150 feet, thinning west.
Kellaways Rock: Thick-bedded ferruginous soft Sandstone, calcareous above, and argillaceous below, passing into dark shales of Cornbrash Clays (see Mr. Leckenby, in 'Q. J. G. S.,' vol. xx. p. 4; Mr. W. H. Hudlestone, in 'P. G. A.,' vol. ii. p. 363): 6 feet at Newbiggin Wyke, thickens westwards, 30 feet at Gristhorpe, 75 at Scarborough North Cliff.

The Upper Oolite consists of—

Portland Beds: Band of Coprolites, with Saurian remains.
Kimmeridge Clays: Borings have found 50 feet at Knapton; the water from it is salt, but does for cattle.

The Cretaceous rocks are the—

White Chalk: Flaggy and hard, trends of flint and clay in lower part. Water rose 5 feet above surface at well at Butterwick, 119 feet deep.
Red Chalk: 20 to 30 feet; springs are thrown out by underlying clays.

Upper Neocomian Clays ..	Determined by Professor Judd, and making a thickness at Speeton of no less than 500 feet, according to him.
Middle „ „	
Lower „ „	

O.S. CATCHMENT BASIN XL.

These streams occupy 206 square miles, underlaid by chalk, covered with the thick deposits of Glacial Drift, forming the characteristic feature of the coast of Holderness. The rainfall in 1879 at Patrington was 25·8. The chief places are Patrington, Aldborough, Garton, Welwick, and Marfleet.

RIVER HULL (XXXVIII.).

This river has a length of 20 miles; area, 364 square miles, consisting of chalk overlaid by Glacial Drift alluvium. The rainfall in 1879 at Beverley was 27 inches.

KINGSTON-UPON-HULL. — Population, 154,250; supply from the chalk by artesian borings; pumping station at Springhead (4 miles west from Hull); two wells, 5 borings, 250 to 410 feet deep, and 15 to 20 inches diameter; service reservoirs of 9,000,000 gallons capacity; supply 6,000,000 gallons; average consumption, 5,500,000 gallons (c.); rateable value, 520,869*l.* (Besides the Waterworks Clauses Act of 1863) the Kingston-upon-Hull Water Acts 1843, 6 & 7 Vict. c. 73; 1872, 35 & 36 Vict. c. 200.

GREAT DRIFFIELD.—Population, 5937; pumps and wells; rateable value, 21,922*l.*

BEVERLEY.—*Acres*, 2228; population, 11,442; the chalk bed of the Wolds, lying under the town; wells public and private; rateable value, 30,318*l.* Rainfall at 62 feet above Ordnance Datum 26·9, in 1879.

WALLINGFEN.—*Acres*, 5161; population, 1005; old part from a running stream; new part from wells; rateable value, old part, 11,908*l.* 1*s.* 6*d.*; new part, 3974*l.* 17*s.* 8½*d.*

COTTINGHAM.—*Acres*, 9500; population, 6236; Cottingham proper from private pumps, artesian bores; Newland portion from the Newington Waterworks Company, at 5*l.* per cent. on the rental; rainfall in 1879, 22·7; rateable value, 42,445*l.*; Newland Waterworks Company, 1875 (38 & 39 Vict. c. 169).

HEDON.—*Acres*, 237; population, 966; from springs and artesian wells; rateable value, 3182*l.* 15*s.*

NEWINGTON.—*Acres*, 1340; population, 8038; Newington Waterworks Company (Limited); tanks on 2 towers; 2 artesian wells, 1 not finished; rateable value, 22,000*l.*

The chalk of Yorkshire is chiefly drained by the River *HULL;* west of this basin, about 90 miles drain into the *Derwent* and *Foulness;* 88 miles drain northwards and eastwards to Flamborough Head and Bridlington Bay, and 206 miles southwards into the mouth of the *HUMBER.* This tract, as well as a large portion of the two former, is deeply covered with the Glacial Drift of Holderness, chiefly consisting of impermeable clays, 50 to 200 feet in thick-

ness, their surface rising to 100 feet above the sea-level, and their base sinking to 130 feet below it, the upper portion forming the cliffs of Bridlington and Spurn. At Hornsea the chalk is stated by Mr. J. R. Mortimer* to be 800 feet thick, overlaid by 130 feet of impermeable Boulder Clay, and resting on impermeable Kimmeridge and Neocomian Clays, occurring at a depth of 910 feet below the sea-level, and forms a basin, on which rest the water-charged chalk and drift clays of Holderness. At Malton the base of the Kimmeridge clay was not reached in a boring of 460 feet; or at Norton Villa, at a similar depth. The water absorbed from rainfall forms a somewhat undulating inclined plane, following the slope of the chalk hills towards the sea and *HUMBER* on one side, and towards the Vale of Pickering on the other. The total area of chalk exposed so as to form an area of absorption is 420 square miles, with an average annual rainfall on the Chalk Wolds of 27½ inches, of which Mr. Mortimer considers ¾ is absorbed; a very high estimate. The water carried down beneath the Boulder Clay rises with great violence along the sea-margin after heavy rains, as near Bridlington Harbour, in the bed of the *HUMBER* between Hull and Hessle, where the bubbling noise has given it the name of the Hessle Whelps. In borings made at Hessle, Anlaby, and Springhead, the level of the water rises and falls with the tides, as was the case in a well made in 1823 at about the site of the entrance of the Albert Dock, Hull, by Mr. W. Oldham, of Cottingham, who states the chalk was reached at 110 feet below the surface, and penetrated 22 feet.

Mr. Villiers, of Beverley, reporting to Mr. Mortimer on various borings in the chalk at Hull and Sunk Island, states they all yield more or less brackish water, the freshest being over 95 feet deep, whilst another, only 20 yards from it, and 300 feet deep, contains 20 per cent. more salt; and a boring put down in 1846 by Messrs. Easton and Amos, at Sunk

* 'Min. Proc. Inst. C. E.,' vol. lv.

Island, for the Commissioners of Woods and Forests, failed to reach water free from salt at 330 feet.

The sinuous line of western boundary of the clay rises from the sea-level at Hessle, to 50 feet above the sea-level, at Lockington and Cranswick, to 75 at Kirkburn; thence it descends to 70 feet at the source of Emswell Beck, to 52 feet west of Driffield Station, and to 55 feet at Nafferton; thence by Burton Agnes and Carnaby to the sea, at Bridlington Quay, the saturation level in the chalk both in dry and wet weather, along the line of boundary coincides with the top of the chalk, so that the latter beneath the drift is always fully charged. Westwards the rise of the water is at an angle less steep than that of the slope of the country, the gradient decreasing during droughts. The surface of the impermeable Neocomian and Kimmeridge clays beneath the chalk rises from the sea-level, in the *HUMBER* at Welton to 475 feet, at Kirkby-under-Dale to 510 feet east of Mount Farrant, to 600 feet north of that place and to 450 feet at Grimston Hill, then descending rapidly to 175 feet at Knapton, and at High Mill, Sherburne, and passing down to the sea-level north of Flamborough Head.

The crest of the chalk water, or underground watershed, runs parallel to and not far from the boundary of the clays just described, rising to a height of nearly 600 feet east of Mount Farrant.

In 1872 the rainfall of Little Driffield was 40·19 inches, causing a copious flow of water in the following autumn and beginning of 1873, of the Wold 'Gypsey Races,' corresponding to 'the Bournes' of the south coast chalk. The most important of these rises at Oxcroft Spring, 400 feet above the sea, close to the western clay margin at Duggleby, crossing the chalk to the other clay margin at Bridlington Quay, where it reaches the sea; from Duggleby to Thirkleby its course is permanent, and it has descended to 100 feet; thence by Boythorpe 200 feet, Foxholes 175 feet, N. Burton 124, and Rudston 100 feet. It only appears after wet

weather between Boythorpe and N. Burton, being known as the Lords' River. Its course is distinctly parallel to the western clay margins. The surface of the underground chalk water descends towards the Gypsey Valley, so that here there are subterranean watersheds, the one in the chalk hills lying between the clays under the chalk margin and the Gypsey Valley, the other in the chalk hills situated between the Gypsey Valley and the clays lying over the chalk. The top water-level beneath the Gypsey Valley only rising above the bottom of the valley after very wet weather.

Mr. Mortimer states the rainfall of Little Driffield was 40·19 inches in 1872, causing a copious flow of the 3 Wold Gypsey Races. In 1873 and 1874 the fall was only 21·46 and 23·19 inches respectively, the springs and ponds dried up, and the chalk water belt was reduced, a large number of wells had to be deepened, and much distress resulted. In 1875 there was rather a larger rainfall, and in 1876 the fall at Malton was 29·74, and at Langtoft (on the northern edge of the Wolds, 150 feet above the sea-level) 32·065, this produced a copious flow of the races, and a greater rise of the water-level than in the autumn of 1872. In the drought of November and December, 1874, the water in the Langtoft well sunk to 130 feet below the surface, and the well had to be deepened, rising on the 9th January, 1877, to only 27 feet from the surface, showing a vertical seasonal variation of 103 feet. On the same date the water in the Cowlam well, 430 feet above the sea, 2½ miles W.S.W. of Langtoft, stood at 270 feet above Ordnance Datum, or 108 feet above that of Langtoft. On the edge of the Holderness clay the rise and fall of the water-level is only 10 or 15 feet, and under the clay the level is constant, the water being held in by the clay.

RIVER FOULNESS (*XXXIX.*).

The length of this river is 14 miles; area, 133 square miles, of which 72 miles are occupied by Triassic rocks, 10 by lias, 8 by oolite, and 43 by chalk. The rainfall was 25·79 inches in 1879 at Holm-on-the-Wolds near Market Weighton, at an

elevation of 154 feet above the sea. Other chief places, South Cave and Welton. The eastern feeders of this stream rise on the escarpment of the chalk, above Goodmanham Spa Mill, and flow south on the underlying clays, and feed the Market Weighton Canal.

Central Group:—Streams above the infall of the River *TRENT* into the *HUMBER:*—

RIVER DERWENT.

This river, with its tributaries, occupies an area of 794 square miles, of which 57 consist of oolite, 12 of Greensand, and 88 of chalk. Its length is 64 miles. Rainfall 31 to 34 inches at Pocklington in 1879. Other chief places, Barnby, Ellerton, and New Malton. Its tributaries are the *Rye*, 28 miles in length; chief places, Slingsby, Nunnington, 89 feet; Great Helmsley, 176 feet: the *Seven* 13 miles long; chief places, Marton, Appleton-le-Moor: the *Seph*, 10 miles in length, ranging in elevation from 310 feet to 1427 feet at the watershed: the *Hertford* 7 miles in length. Chief places: Tedlington, Brompton, Hutton Bushell, 125 feet.

Sanitary authorities in the *DERWENT* basin:—

Malton.—*Acres*, 6640; population, 8750; pumped from closed well (springs) into covered reservoir, $50 \times 60 \times 12$ feet; about 110,000 gallons (c.); rateable value 31,240*l.*; Local Government Act, 1858. Rainfall in 1879 at 75 feet above the sea, 23·28.

Pickering.—*Acres*, 14,280; population, 3959; ordinary wells and pumps in street; there is also a private Water Company; reservoir supply constant; rateable value, 15,219*l.* 5*s.*

Hinderwell.—*Acres*, 1655; population, 2467. Hinderwell, one public and many private wells. Runswick, two public springs or small streams. Port Mulgrave, a public well or two, and in dry weather from Staithes Beck. Staithes, from the beck or stream; rateable value 4636*l.* 4*s.* 9*d.*

RIVER OUSE (*XXXV.*).

This river has an area of 1842 square miles, of which 960 consist of Carboniferous rocks, 50 of Magnesian Limestone, 500 of Trias, 90 of Lias, and 42 of Oolites. Its length is 40 miles; chief places, Selby, 18 feet; Cawood, 22 feet; York, Skelton, Ouseburn, 41 feet.

York.—*Acres*, 1962; population, 54,198; supply from the River *OUSE*, above the city: is pumped from the river into subsiding tanks, then filtered through beds of sand and gravel, and afterwards pumped to a high service reservoir, from which it is distributed through the district, by means of mains and service pipes; about 1,800,000 gallons (c); rateable value, 163,275*l.*: the York New Waterworks Act, 1846; the York New Waterworks Act, 1876. Rainfall, 1879, 22·9.

Whitwood.—*Acres*, 1080; population, 4110; springs and wells; rateable value, 19,763*l.* 9*s.* 10*d.*

Selby.—*Acres*, 3258; population, 6033; artesian well pumped by an engine into a cast-iron tank, thence distributed by ordinary service pipes; 136,000 gallons (c.); rateable value, 18,077*l.* 15*s.*

Mr. Wetherill, the manager of the works, states the well is 20′ 6″ above mean tide-level. The bottom of the bore-hole is 330 feet from the surface, and water rises before pumping to within 4 feet of it; the yield is 250,000 gallons, and the level is recovered in two hours. The water is above 8° of hardness, and is pure in quality. Drift occupied 75 feet, and the remainder was red and grey New Red Sandstone, of the total thickness of 255 feet; the bottom beds are described as very hard, so it would appear the Lower Mottled Sandstone was not reached.

The tributaries are the *Foss*, 16 miles long; chief places, Strensall, Stillington: *Wiske*, 12 miles long; chief places, South Otterington, Northallerton; highest point of watershed about 198 feet: *Swale*, 64 miles long; chief places, Cundall, 62 feet above the sea; Topcliffe, Pickhill, Richmond: *Wharfe*, 65 miles long; chief towns, Tadcaster, Wetherby,

61 feet; Harewood, 122 feet; Otley, Ilkley, Kettlewell, 691 feet.

NORTHALLERTON (*Wiske*).—*Acres*, 90; population, 3692; supply from wells dug in the ground belonging to each dwelling-house or block of dwelling-houses; no waterworks; rateable value, 690*l*. Rainfall in 1879, 23 inches.

KIRKLINGTON-CUM-REPSLAND.—*Acres*, 2000; population, about 249; supply from ordinary wells, from springs, generally in the Red Sandstone, 6 to 11 yards deep; rateable value, 339*0l*. 5*s*.

RICHMOND (*Swale*).—*Acres*, 1843; population, 4502; two springs, 2 miles distant from the town; two reservoirs have been made 100 feet above the level of the town to store 100,000 gallons for pressure, supply 160,000 gallons (c); rateable value, 16,320*l*. Rainfall, 29·84 in 1879.

Nidd, 47 miles long; chief towns, Knaresborough, 145 feet, Ripley, (Harrogate),* Pateley Bridge, 394 feet.

KNARESBOROUGH and TENTERGATE (*Nidd*).—*Acres*, 481; population, 5000; the River *Nidd* filtered 11,000 gallons per hour, pumped from the river, distant about 3 yards, and it passes from the pump to a subsiding reservoir; 14 hours' supply of 104,000 gallons; rateable value, 11,968*l*.; 4 Geo. III., 1763, "for better supplying the town of Knaresbro' and Tentergate with water;" also under the Local Government Acts.

BAILDON.—*Acres*, 2605; population, 5430; from springs; three reservoirs; rateable value, 13,676*l*.

BURLEY.—*Acres*, 4057; population, 2550; springs never dry; reservoir; rateable value, 11,400*l*.; Burley Local Board Waterworks Act, 1873.

HARROGATE.—*Acres*, 1287; population, 9482; Haverah Park, near Harrogate; by the Harrogate Waterworks Company; rateable value, 57,000*l*. Rainfall, 1879, 31·3.

GUISELEY (*Wharfe*).—*Acres*, 1525; population, 3706; Waterworks; by reservoir supplied by springs reached by

* Names of towns in parentheses are situated within the basin of the stream mentioned, but are *not* built on the banks or in the immediate valley of that stream.

boring and drifts into the Sandstone rock; (c.) except in drought; rateable value, 11,614*l.*; Company's Acts.

Horsforth.—*Acres*, 2820; population, 6346; from springs and rainfall, from drainage area in the district; reservoir; 80,000 gallons per day (c.); rateable value, 19,100*l.*; under Act dated June 2, 1865.

Ilkley.—*Acres*, 3822; population, 4753; from springs on moor; water conveyed from springs in iron pipes to 3 service reservoirs; then by gravitation to town; supply, 250,000 gallons (c.); rateable value, 26,873*l.* 14*s.* 2*d.*; the Ilkley Waterworks Act, 1871. Rainfall in 1879, 27·3.

Otley.—*Acres*, 2233; population, 6803; streams, reservoir; supply, maximum 200,000 gallons; minimum, 150,000 gallons; average about 160,000 gallons (c.); rateable value, 22,316*l.*; the Public Health Act.

Ure, 54 miles long; chief places, Boroughbridge, 58 feet; Ripon, 72 feet; Masham, 261 feet; Leyburn, 365 feet; Askrigg; Hawes, 746 feet. Tributaries of the *Ure:* the *Skelt*, 12 miles long; the *Cover* 9 miles long; chief places, Middleham, and East Witton: the *Bain*, 4 miles long.

Masham (*Ure*).—*Acres*, 16,759; population, 2174; generally from springs, and spout springs, draw wells and pumps, also an artesian well (c.); rateable value, 16,224*l.* 19*s.*

Ripon.—*Acres*, 1580; population, 7391; the River *Ure* pumped into service reservoir; pressure sufficient to reach roof of highest house in town; the water passes through filter-beds; all public wells, and most of the private wells, are now closed after analysis; 25 gallons per head; rateable value, 27,029*l.* 7*s.* 6*d.* The works designed by Mr. G. W. Stevenson, C.E., approved by Mr. Filliter, C.E. (of Leeds), and now being completed by Mr. Hawksley. Rainfall in 1879, 28 and 29 inches.

CHAPTER V.

CENTRAL HUMBER BASIN.

AIRE (*XLIII.*).

THIS river and its important tributary the *Calder* drain a triangular tract of country 815 square miles in extent, of which the high watershed of the Pennine chain, ranging from the hills overhanging Oldham to those above Settle, forms the base of the triangle, and the infall of the river into the *OUSE* between Goole and Selby the apex. The river is 78 miles long, rising in the underground streams in the Carboniferous Limestone of Malham Cove. The watershed reaching in Pennegent a height of 2273 feet, descending in a few miles to 580 feet, where the Settle and Skipton Railway crosses into the *RIBBLE* valley, at a point west of Gargrave, and still lower where the Leeds and Liverpool Canal and the Colne and Skipton Railway crosses, where it is 456 feet, then it again rises to 1383 feet, between Colne and Bingley. Southward the Fells run a considerable height, but are breached by a remarkable transverse valley, or col, between Burnley and Todmorden, through which the railway is carried, the Yorkshire and Lancashire *Calders* rising at either end. From this valley another valley extends southwards, also traversed by a watershed, which has been taken advantage of for the Todmorden and Rochdale Railroad; on the southern side of the watershed rises the *Roch*, tributary of the *Irwell*. Still further south, between Oldham and Huddersfield, the watershed rises to 1533 feet. South of this point the Pennine watershed forms the western boundary, first of the *Don*, and then of the *Derwent*, and other tributaries of the *TRENT*. From its source, by Gargrave, Skipton, and nearly to Keighley, the river flows over

the Carboniferous Limestone which occupies 10 square miles. Thence, by Bingley, 224 feet above the sea, and Yeadon 160 feet (river), Leeds 112 feet, and Castleford 56 feet, it traverses the Carboniferous Rocks, including the Yoredale and Millstone Grits and the Coal Measures, occupying 665 square miles, a large portion of which is drained by the *Calder*, which falls into the *AIRE* just above Castleford. Thence the river flows over 44 square miles of Magnesian Limestone, and 96 of New Red.

Skipton.—*Acres*, 4245; population, 9091; supply 200,000 gallons from four reservoirs with joint capacity of 53,000,000 gallons; rateable value, 20,000*l.*; Skipton Local Board of Health, 1874. The following observations of Mr. A. R. Binnie give the rainfall of the Skipton Waterworks area in 1879 and 1880, and show on the whole a gradually diminishing amount with decrease of elevation:—

	Feet.	1879.	1880.		Feet.	1879.	1880.
Barden Upper Reservoir	1250	35·16	46·22	Barden Reservoir	746	35·62	47·80
Counters Hill ..	951	25·18	33·33	Chelkers „	730	23·96	34·30
Cringle's Reservoir	760	24·12	32·11	Silsden „	560	23·32	31·32

Emley.—*Acres*, 3556; population, 1290; from wells and springs; rateable value, 6152*l.* 14*s.*

Flockton.—Population, 1180; field drainage collected in reservoirs; rateable value, 3426*l.*

Yeadon.—*Acres*, 1660; population, 6533; supply, 66,000 gallons from reservoirs, with storage of 6 million gallons or 91 days' supply; 70,000 gallons can be pumped daily from wells; rateable value, 16,266*l.*; the Yeadon Waterworks Company's Act, 1870.

Keighley.—*Acres*, 1820; population, 25,245; supply, 1,100,000 gallons from springs and streams in the Forest of Trawden and from springs near Keighley, collected in one large and two small storage reservoirs, passed through a filtering reservoir; rateable value, 75,000*l.*; Keighley Waterworks Acts, 1867, 1869, and 1872.

Oakworth.—*Acres*, 15,124; population, 5759; partly

from Keighley Local Board at 5*d.* per 1000 gallons, partly from wells and springs; rateable value, 16,718*l.*

Oxenhope. — *Acres*, 4080; population, 2443; springs; there is a compensation reservoir for mills; rateable value, 5767*l.*

Bradford. — *Acres*, 7221; population, 183,032. The Bradford Corporation water supply is derived from the following gathering-grounds: about 12 square miles on two tributaries of the *Wharfe* on the north side of the river, and 7½ square miles on three tributaries on the south side of the river, a third area of about 8 square miles on tributaries on the north side of the *Aire*, above Bingley, and a fourth area, south of that river, about 4½ miles in extent. In all, 10,650 acres (Bateman). The watershed separating the latter from the *Calder* marks the boundary of the Bradford Waterworks area from the Halifax Waterworks gathering-ground, collecting the rainfall falling on the tributary of the *Calder* passing through Halifax, and of the streams falling into the *Calder* above it. A tributary still higher up, rising in the Pennine watershed, being also brought into requisition, and forming a second area, overhanging that occupied on the other side of the ridge by the gathering-grounds of Burnley and Kelson, in all 2600 acres.

The Rivers Pollution Commission, describing the works, states there are three distinct services, viz., a *high-level* derived from Millstone Grit (Stubden Reservoir) with 6·4 degrees of hardness, turbid from peat; an *intermediate* service also from the Millstone Grit, but partly from springs in it, with 6·5 degrees of hardness (at Manywell's spring); and a low-level service, also chiefly derived from Millstone Grit, but partly from Limestone, with 7·1 degrees of hardness (Heaton Reservoir). All these samples contained less than 1·30 part per 100,000 of chlorine. The Waterworks have cost 1,100,000*l.*; the supply in Bradford is 24 gallons per head for domestic purposes and 20 gallons for trade purposes, or from 8¼ to 8½ million gallons per day. The

rateable value of Bradford is 857,097*l.* The works were carried out under the Bradford Corporation Waterworks Act, 1854; Amendment Act, 1855; Acts of 1858, 1862; Waterworks and Improvement Act, 1868; Waterworks Act, 1869; Improvement Act, 1873; Waterworks and Improvement Acts, 1875 and 1878. Rainfall in 1879 was, at the Exchange, 28·02; at Heaton Reservoir, 30·14, 530 feet above Ordnance Datum; at Hewenden Reservoir, 700 feet, 30·73; at Brown Royd Reservoir, 385 feet, 28·97; at Thornton Moor Reservoir, 1176 feet, 1·68, according to Mr. A. R. Binnie, C.E.

The following urban authorities receive the *Corporation supply*:—

Thornton. — *Acres*, 3295; population, 6084; supply, 14,433 gallons; rateable value, 12,848*l.* Tong, population, 5600; constant supply; rateable value, 18,336*l.* 17*s.* 7*d.* Bingley (Township), population, 9465; supply, 20,000 gallons, part from Bradford, part from Keighley Local Board and the village of Cullingworth, by springs impounded by Local Board of Bingley. Bingley (Improvement Act District), *acres*, 909; population, 8972. Under Bingley Improvement Act the Board buys water by meter of Bradford Corporation, rents water of William Ferrand, Esq., at 600*l.* per annum, and water-pipes of George Lane Fox, Esq., at 30*l.*; in all 863*l.* 4*s.* per annum; rateable value, 22,844*l.* 6*s.* 8*d.* Birstall, *acres*, 1500; population, 6768; constant supply, 100,000 gallons; Local Board have distribution reservoir; rateable value, 17,526*l.* 14*s.* 8*d.* Silsden, population, 3329; constant, 11,000 gallons; rateable value, 3700*l.* Clayton, *acres*, 1200; population, 4301; constant supply, 5890 gallons; rateable value, 9805*l.* Cleckheaton, *acres*, 1652; population, 10,653; constant supply of 150,000 gallons; rateable value, 34,000*l.*; Public Health Act. Eccleshill, *acres*, 1220; population, 7037; supply constant of 55,000, reduced in 1874 to 12,000, causing much sickness; rateable value, 18,836*l.*; Provisional Order of Local Government Board. Heaton, *acres*, 1323; population, 3106; supply constant, 15,000 gallons; rateable value, 13,223 2*s.* 6*d.* Hunsworth, *acres*,

1081; population, 1516; supply constant of 1685 gallons, except in drought. This Board complains of the price charged by Bradford, who supply 150,000 persons outside the municipal borough, at any rate they choose; rateable value, 12,472*l.* North Brierly, *acres,* 4541; population, 20,938; supply constant, except in drought, of 129,676 gallons; rateable value, 49,822*l.* Drighlington, *acres,* 1051; population, 4213; supply constant of 50,000 gallons; rateable value, 11,000*l.* Gildersome, *acres,* 993; population, 3470; supply constant of 22,000 gallons, through Drighlington main, for the use of which interest is paid; rateable value, 9684*l.*

Calverley.—Population, 3771; supply from Bradford, through *Calverley District Waterworks;* rateable value, 16,024*l.* These Works supply:—

Farsley.—*Acres,* 861; population, 4434; rateable value, 11,970*l.* Idle, *acres,* 1600; population, 6643; supply constant; rateable value, 21,811*l.* Pudsey, population, 15,459; supply constant; rateable value, 38,000*l.* Denholme Gate, *acres,* 2653; population, 3549; supply constant from Bradford, through private firm, Messrs. W. and H. Foster; rateable value, 9727*l.*

Gomersal.—Population, 3986; supply constant from Bradford, through the *Gomersal Waterworks Co.* (Limited); rateable value, 14,359*l.*

This Company supply:—

Birkenshaw.—Population, 2699, with rateable value, 9806*l.* Allerton, *acres,* 1970; population, 2903; supply, 24,175 gallons, through *Allerton Waterworks Co.* (Limited); rateable value, 10,254*l.* 10*s.* Liversedge, population, 12,743; through *Rawfolds District Water Supply Co.* (Limited); rateable value, 35,862*l.*

Leeds.—*Acres,* 21,572; population, 309,126. The supply is constant, and is taken from gathering-grounds at Eccup, and from the River *Washburn* at Leathley (tributary of the *Wharfe*), and from the River *Wharfe* at Arthington. The yield is about 14,000,000 gallons, and the quantity used

about half that quantity. The Woodhouse storage reservoir holds 6,000,000 gallons. The largest is that at Eccup, near Leeds, holding 257,000,000 gallons. The water is filtered at the Westwood reservoir, near Leeds, holding 22,000,000 gallons. The first Act of Parliament was obtained by the Leeds Waterworks Co. in 1837 (1 Vict. c. 83), and the works extended under 10 & 11 Vict. c. 262, 1847. The interests of the Company were purchased by the Corporation, under the Leeds Waterwork Act (*Wharfe* Supply), 1852, and additional works under Acts of 1862, 1867, 1874, and 1877. Rateable value, 1,051,396*l.* The works cost 535,620*l.*

The Eccup reservoir drains 1200 acres, and the water from it and the *Washburn* is said to be free from pollution, but that from the *Wharfe* receives, above the intake, some of the sewage of Otley, Burley, Ilkley, and Addingham. The water from this source is filtered through 18 inches of sand. The Rivers Pollution Commission analyzed a sample of the Eccup supply. It was rather peaty, but pure and clear, and of 8·3 parts in 100,000 of total hardness, of which 6·5 was permanent. Chlorine was 1·80.

Leeds Corporation supply:—

Morley.—*Acres*, 2699; population, 15,016; constant supply of 72,000 gallons for domestic, and 84,000 for trade purposes, at 7½*d.* per 1000, up to 250,000 gallons; rateable value, 46,700*l.*; Public Health Act. Rothwell, with Rothwell Haigh and Royd's Green, *acres*, 3190; population, 5103; supply 10,000 to 12,000 gallons at 7½*d.*; small service reservoir, containing twenty-four hours' supply; rateable value, 26,920*l.* Churwell, *acres*, 456; population, 1973; constant; small distribution reservoir; rateable value, 7518*l.* 5*s.*

Castleford.—*Acres*, 564; population, 10,523; Local Board supply from a well, yielding 80,000 to 150,000 gallons; rateable value, 30,000*l.*; Public Health Act, 1848.

Featherstone.—*Acres*, 4426; population, 5901; shallow wells; rateable value, 311,361*l.* (?)

Methley.—*Acres*, 3492; population, 4073; wells; rateable value, 25,000*l.*

SOYLAND.—*Acres*, 4960; population, 3467; public wells; rateable value, 11,517*l.*

WARLEY.—*Acres*, 3240; population, 3211; no public supply; rateable value, 12,009*l.* 3*s.*

MIDGLEY.—*Acres*, 2000; population, 2939; artesian wells; rateable value, 10,240*l.*

NORTH OWRAM.—*Acres*, 1500; population, 3294; springs and wells; rateable value, 9766*l.*

OVENDEN.—*Acres*, 5350; population, 4786; springs and wells; rateable value, 2227*l.* 2*s.* 1*d.*

QUEENSBURY.—*Acres*, 1536; population, 6825; springs and wells; rateable value, 17,197*l.*

PONTEFRACT.—*Acres*, 3160; population, 8798; supply pumped from wells, yielding 13,000 to 15,000 gallons per day; rateable value, 27,976*l.*; works carried out under Street Act of 1810, and enlarged by Local Act, 1869.

The Rivers Pollution Commission states the well of the Waterworks Company at Tanshelf is 7 feet in diameter, and sunk in the Magnesian Limestone 40 feet, yielding 70,000 gallons per day of 10 hours, uncovered. Cherwood service reservoir holds 18,000 gallons.

Locality.	Chlorine.	Total Hardness.
Baghill pump-water	3·45	66·0
New Borehole at Waterworks ..	4·35	55·2
Water Supply, 1872	5·55	67·3
Spring in Waterham's field ..	3·40	59·7

All the samples show traces of excessive past pollution, and were more or less derived from soakage of sewage or manured land, and all were too hard for habitual use, the excessive and permanent character of it being likely to cause calculus.

River Calder.

This river is 43 miles long, rising in the eastern slope of the Pennine chain, ranging between Bacup and Todmor-

den; thence it flows over Carboniferous rocks, by Sowerby, Halifax, Elland, Dewsbury, Wakefield, at 86 feet, and falls into the *AIRE* at Castleford at 56 feet. In the hilly country between the *AIRE* and the *Calder* are the towns of Bradford, Batley, Cleckheaton. South of the river, and half-way between it and the *Don* watershed, is the town of Huddersfield. A canal follows the line of this stream from Wakefield. It commences at 68 feet, rises to 93 feet between Wakefield and Dewsbury, 155 feet between Dewsbury and Sowerby, 232 feet south of Halifax, 344 feet between Sowerby and Todmorden, 610 feet on the watershed, from which it follows the valley of the *Roch*, descending to 498 at Rochdale. A line of railway runs parallel to this canal the whole distance.

Todmorden.—*Acres*, 15,790; population, 23,861; no public supply; rateable value, 69,835*l*.

Halifax.—*Acres*, 3769; population, 73,633; supply is about 2,650,000 gallons to the borough, and 700,000 gallons sold daily to Local Boards. The storage reservoirs are at Ogden, Luddenham, and Hebden Brook. The works were carried out under the Halifax Improvement Acts of 1823, 1853, 1858, and Halifax Corporation Waterworks Act, 1868. Rateable value, 270,202*l*.

Supplied by the *Halifax Corporation*:—

Hipperholme.—Population, 2920; supply 30,000 to 80,000 gallons; rateable value, 14,047*l*. Horbury, *acres*, 1279; population, 5050; constant; 25,000 gallons; rateable value, 24,557*l*.; Horbury Local Board Act, 1874.

Mr. Bateman gives a diagram showing the flow of the water in the Halifax Corporation Waterworks Extension in 1868, from which it appears that *Walshaw Dean*, draining 2325 acres, running 57 cubic feet per second per 1000 acres on some days in January and February, in May, June, July, and August, never reached more than 2 cubic feet—May averaging 0·554 cubic foot per second, June 0·28 cubic foot, July 0·225 cubic foot; three weeks of August 0·272 cubic foot, or an average of the whole drought of 0·332 cubic foot per 1000 acres of drainage.

Widdop Water and *Greave Clough*, draining 1999 acres, during the same drought averaged 0·416 cubic foot per second per 1000 acres, whilst running 57 cubic feet in one day of March.

River Hebden, at Lord Holme Mill, draining 9322 acres, running 100 cubic feet on several days in January, February, and March during the same drought, averaged 0·452 cubic foot per second per 1000 acres of drainage.

Hebden Bridge.—*Acres*, 257; population, 5008; from Widdup reservoir, 15,000 to 20,000 gallons; rateable value, 16,362*l.*; Public Health Acts.

Brighouse.—*Acres*, 420; population, 7964; 76,000 to 120,000 gallons; rateable value, 26,203*l.*

Elland.—*Acres*, 1338; population, 8278; 65,000 to 195,000 gallons; rateable value, 28,917*l.*

Greetland. — Population, 4194; Corporation supply 20,000 to 30,000 gallons; perhaps a quarter of the supply is derived from public, ordinary, and artesian wells; rateable value, 12,288*l.*

Sowerby Bridge.—*Acres*, 528; population, 8721; supply constant; rateable value, 34,903*l.* 19*s.*; 26 & 27 Vict. 1863.

Rastrick.—*Acres*, 1290; population, 8038; 61,600 to 75,000 gallons; rateable value, 22,230*l.* 13*s.*

Soothill Nether. — *Acres*, 362; population, 5240; 45,000 to 65,000 gallons; rateable value, 11,106*l.* 16*s.* 6*d.*; Public Health Act, 1848.

Soothill Upper.—Population, 5155; from service reservoir at Thornhill, 120,000 gallons are received, but only 65,000 used, remainder sold to Local Boards of Soothill Nether and Horbury; rateable value, 20,081*l.*

Thornhill.—*Acres*, 3602; population, 8843; 55,000 gallons; rateable value, 25,367*l.* 15*s.*

Luddenden Foot.—Population, 2891; wells; rateable value, 10,668*l.*

Rishworth.—*Acres*, 7000; population, 1110; springs and wells; rateable value, 3800*l.*

Shelf.—*Acres,* 1350; population, 2754; private and public wells; rateable value, 7517*l.* 11*s.* 3*d.*

South Owram.—*Acres,* 1200; population, 3036; springs and wells; rateable value, 11,009*l.* 12*s.* 3*d.*

Sowerby.—Population, 6177; wells and springs; rateable value, 18,963*l.*

Dewsbury.—*Acres,* 1468; population, 29,617; supply 300,000 to 600,000 gallons, pumped from the *Don* and *Dearden,* streams at Dunford Bridge, constructed originally under the Dewsbury, Batley, and Heckmondwike Waterworks Acts, 1856, 1861, and 1867, now carried out under "Dewsbury and Heckmondwike Waterworks Act, 1876," which Act allows the purchase of the share of the supply taken by Batley; rateable value, 88,209*l.* Ravensthorpe, *acres,* 358; population, 4363; intermittent supply of 30,000 gallons from Dewsbury; rateable value, 16,823*l.* 10*s.* 10*d.* Heckmondwike, population, 8302; joint supply with Dewsbury from reservoirs at Dunthorpe Bridge, near Sheffield, Broadstones, and well head; quantity, 250,000 gallons, intermittent; rateable value, 26,064*l.*

Normanton.—*Acres,* 1226; population, 6319; supply, 30,000 gallons, pumped from St. John's Colliery, near Wakefield; rateable value, 30,000*l.*

Haworth.—Population, 3816; two small reservoirs storing springs, intermittent supply of 29,000 gallons; rateable value, 6316*l.* 7*s.* 6*d.*; Public Health Act.

Batley.—*Acres,* 2038; population, 27,514; supply stored in reservoirs on the moors, near Holmfirth, yields 300,000 gallons for domestic supply and 600,000 for trade purposes; two other reservoirs are authorized by Batley Corporation Waterworks Act, 1871; rateable value, 77,470*l.*; rate, 6*d.* in the pound.

Shipley.—Population, 15,089; springs, stored in reservoir, yield constant supply of 550,000 gallons; rateable value, 48,788*l.* 4*s.* 6*d.*; Shipley Sanitary Act, 1874.

Windhill.—*Acres,* 700; population, 6732; supplied by Shipley Local Board, under the Waterworks Act, 1854 (17 & 18 Vict. c. 77.)

Wilsden.—*Acres*, 2607; population, 2967; springs; rateable value, 8000*l.*

Mirfield.—Population, 11,512; constant supply from Huddersfield Corporation; rateable value, 35,000*l.*

Wakefield.—*Acres*, 1554; population, 30,573; supply from Joint Stock Company, established in 1837, reservoir at Stanley Fell, 2 miles from Wakefield, 1,000,000 gallons are pumped daily from the River *Calder*, at a point where it is polluted by town sewage, liquid refuse from manufactures, chemical works, gasworks, dye and bleach works, tanyards, and also by mines, not only in districts higher up the stream, but from the town itself; the store reservoir occupies 4 acres, and holds 30,000,000 gallons; the service reservoir is three-fourths of an acre, and holds 3,000,000 gallons; the high service reservoir is built partly above the ground, and is uncovered; the total sold impurity was 40·00; hardness, 13·6, of which 5·8 was permanent;* the water is filtered by Spencer's process; the supply is 1½ million gallons daily; the water now pumped from the *Calder* being derived from springs. The Company, aided by the Corporation, obtained, in 1876, an opposed Bill to obtain their supply from the Oaks rock, and in the valley of the *Dearne*; the pumping station being at Wath, Broomhill, near Wombwell, 21 miles distant by the line intended for the pipes. They have since given up this source for one nearer the town. The rateable value of Wakefield is 117,510*l.* 10*s.*

Tributaries south of the *Calder*, immediately east of Todmorden and the Pennine watershed, supply the reservoir of the Rochdale Canal, which here crosses the watershed, for which a second gathering-ground is situated on the opposite side of the ridge, collecting the southern head waters of the *Roch*. The tributaries of this river to the south form the gathering-ground of the Oldham Corporation supply. Half-way between Halifax and Dewsbury, the south bank of the *Calder* receives, at an elevation of 172 feet, the tributary

* Rivers Pollution Commission, 6th Report.

Colne, 10 miles in length, receiving a rainfall of 27·5; at Huddersfield the rainfall has increased to 31·1, and the *Colne* receives a tributary stream, dividing into two branches, the head waters of which form the two gathering-grounds of the Holme Water Supply, with a rainfall of 37·9.

A canal follows the *Colne* valley, passing Huddersfield at 230 feet, crosses the Pennine watershed at 655 feet, immediately above Saddleworth, where it is carried into the valley of the *Tame*, an affluent of the *Gowt*, a tributary of the *MERSEY*.

Huddersfield.—*Acres*, 10,476; population, 81,825; the water supply is stored in five reservoirs, holding 700,000,000 gallons, on the moors south of the town, fed by catchwater drains; the yield is 3,000,000 to 4,000,000 gallons per day; the actual quantity used varies from 1,500,000, including trade supply, and district supplied in bulk; rateable value, 266,000*l.*

Huddersfield Corporation Waterworks Acts, 1869, 1871, 1876, give powers to supply the following:—Kirkburton.—Population, 3407; supply partly from public artesian well and springs; rateable value, 8490*l.* Kirkheaton.—*Acres*, 1600; population, 2747; within Corporation of Huddersfield supply, which is 3 miles from Market Cross of Huddersfield; rateable value, 8364*l.* 12*s.* Lipton.—Population, 2989 (?); supply partly from public artesian wells and natural springs; rateable value, 6409*l.* Linthwaite.—Population, 6068; supply chiefly taken from springs; rateable value, 1600*l.* Longwood.—*Acres*, 1270; population, 4663; partly from public artesian well; rateable value, 10,100*l.* Marsden-in-Almondbury.—Population, 2634; three-fourths of supply from springs; rateable value, 9375*l.* Marsden-in-Huddersfield.—*Acres*, 3453; population, 686; supply partly from springs; rateable value, 5719*l.*

Meltham.—*Acres*, 4649; population, 4530; reservoir storing springs; rateable value, 15,334*l.* 7*s.*

Netherthong.—Population, 936; springs, public and private wells; rateable value, 4212*l.*

Scammonden. — *Acres*, 1732; population, 607; natural springs; rateable value, 2095*l*.

Scholes.—*Acres*, 723; population, 1155; public and private wells; rateable value, 3445*l*.

Shelley.—*Acres*, 1502; population, 1687; no public supply; rateable value, 3900*l*.

Shepley.—*Acres*, 1204; population, 1594; wells; rateable value, 4702*l*.

Skelmanthorpe.—*Acres*, 1156; population, 3120; pumps; rateable value, 5900*l*.

Slaithwaite.—*Acres*, 3078; population, 3880; springs; rateable value, 13,625*l*.

South Crosland.—*Acres*, 1736; population, 3049; partly from wells and partly from Blackmoor Foot reservoir of Huddersfield Corporation; rateable value, 10,774*l*.

Thurstonland.—*Acres*, 2040; population, 997; dipping wells; rateable value, 4138*l*. 12*s*.

Upperthong. — *Acres*, 3113; population, 2436; Local Authority supply 11,200 gallons from 3 springs; rateable value, 7673*l*. 17*s*.; Public Health Act, 1875.

Whitley, Upper.—Population, 909; from wells; rateable value, 4691*l*.

Wooldale.—Population, 4393; partly from reservoir of Upperthong Local Board, partly from springs; rateable value, 9787*l*. 18*s*.; Public Health Act, 1875.

Barkisland.—*Acres*, 2420; population, 2100; springs; rateable value, 7219*l*.

Honley.—*Acres*, 3435; population, 5070; Local Board, wells; rateable value, 15,731*l*.

Holme.—*Acres*, 1675; population, 678; springs; rateable value, 2786*l*.

THE DON (*XLIX.*).

This river has a length of 57 miles; area, with tributaries, 682 square miles. It rises in the eastern slope of the Pennine chain, at a point opposite to that at which the River

Etherow, a tributary of the *MERSEY*, originates on the western slope. Its western watershed is formed for a few miles by the Carboniferous hills forming the central watershed of England, between Holmfirth and Staleybridge, rising to a height of 1674 feet, where it is met by the minor watershed separating the waters of the *DON* from those of the *Derwent*, and, extending 25 miles S.S.E. to near Belper, traverses the crest of the eastern slope of the *Derwent*. This river flows over the Carboniferous Limestone in the direction of the strike of that rock, which dips under the Yoredale rocks forming the eastern side of the valley, causing the whole of the Carboniferous rocks of the *DON* Basin, occupying 507 square miles, to be newer than the Carboniferous Limestone. At Belper the watershed turns northward, and runs parallel to the base of the Magnesian Limestone, at heights of 287 feet and 426 feet, east of Rotherham, until just before reaching the river it crosses the outcrop of the Magnesian Limestone, which occupies 55 square miles, and runs parallel to the stream, reaching the Lower Mottled Sandstone and Pebble Beds at Doncaster, thence traversing the alluvium of the *OUSE* until it joins the river between the infall of the *DON* and the *TRENT*. The Triassic rocks occupy 120 square miles, part of which is covered with Glacial Drift. The *northern watershed*, unlike the others, is in the direction of the dip of the rocks; it runs roughly parallel to the course of the *Calder*, and thence from Holmfirth, where it is 1142 feet above the sea, it descends to 229 feet south of Dewsbury, and to 220 feet, where the railways from Barnsley cross into the *AIRE* Basin; it is then deflected somewhat northwards, approaching within 2 or 3 miles of the *Calder;* crossing the outcrop of the Magnesian Limestone, it reaches the New Red Series and Alluvium, terminating on the bank of the *OUSE*, between the infall of the *AIRE* and *DON*.

PENISTONE.—*Acres*, 1050; population, 2254; Local Board wells; scheme proposed to tap the *Scout* stream that supplies Barnsley; rateable value, 10,563*l*.

Clayton, West.—*Acres*, 1096; population, 1435; wells; rateable value, 4568*l*.

Denby.—*Acres*, 2713; population, 1557; springs; rateable value, 5060*l*.

Gunthwaite and Ingbirchworth.—*Acres*, 1977; population, 405; supply from *Pun Hill Stream*, and 2 wells; rateable value, 2058*l*.

Thurlston.—Population, 2851; public wells; rateable value, 21,709*l*.

Stocksbridge.—*Acres*, 4335; population, 4660. Supply estimated at 40,000 gallons, from perennial springs, yielding 220,000 gallons daily, flowing into settling tanks, then through 2 miles of 6-inch and 7-inch mains to village tank, holding 40,000 gallons; rateable value, 12,063*l*.

Osset-cum-Gawthorpe. — Population, 10,952; constant supply 60,000 to 70,000 gallons from Batley Corporation, with power to increase supply annually up a maximum of 300,000 gallons. The Batley supply is taken from the Yateholme Valley, near Holmfirth. Rateable value, 30,459*l*. 18*s*. 9*d*.; under Osset-cum-Gawthorpe Local Board Act, 1875.

Sheffield.—*Acres*, 19,651; population, 284,210; supply provided by a private Company from an upland surface of Millstone Grits, covered with peat moors; the head-waters of the *Rivelin* and *Loxley* are intercepted and stored in six reservoirs, holding 1538 million gallons; from thence it flows unfiltered into raised reservoirs holding 25,000,000 gallons. Constant supply is delivered daily of 4,858,584 gallons to 50,000 houses and 700 works. The waterworks cost 1,129,484*l*. The Rivers Pollution Commission states the water is rather peaty, but soft and of good quality; the total solid impurity is 8·36, hardness 4·4, all of which was permanent; chlorine 0·85; Sheffield Waterworks Acts, 1853, 1860–4–7, 1873.

Rotherham.—*Acres*, 5080; population, 34,782; supply constant, 750,000 to 840,000 gallons from Pinch Mill Spring

and Wellgate Spring, and from gathering-ground of 2300 acres, stored in Ulley reservoir, covering 33 acres, with pumping station, and two service reservoirs; rateable value, 100,612*l.*; Rotherham and Kimberworth Local Board of Health Acts, 1863, 1870: and Rotherham Corporation Act, 1875.

Rotherham supplies Rawmarsh, *acres*, 2578; population, 10,179; supply constant, 51,000 to 70,000 gallons; rateable value, 39,858*l.*

Greasbrough.—Population, 2914; no public supply; rateable value, 13,886*l.*

Doncaster.—*Acres*, 1691; population, 21,130; New Waterworks in preparation, present supply from the *DON* and shallow wells. The Rivers Pollution Commission states the *DON* is polluted by Sheffield, Rotherham, and Barnsley, and is dangerous for dietetic purposes. A sample taken at Heathorpe above the town gave total solid impurity, 40·90; hardness, 10·5, of which 7·9 was permanent; chlorine, 6·23. The *Frickley* Stream, and *Hooton Robert's* Brook, also gave bad results; *Barlow* Brook above the Coal Mines, and the streams in Ravensfield Park above the fish-ponds, were better; the latter, though hard (15·5), would make a fair town supply. Its source, a spring in the Park, was of excellent quality, clear, sparkling, colourless, palatable, of moderate hardness, and well suited for all domestic purposes. Total solid impurity, 23·72; hardness, 12·6; nearly all of which was permanent; chlorine, 2·95. Its origin is believed to be in Drift deposits. The town is situated on the junction of the Magnesian Limestone with the underlying Lower Mottled Sandstone. A boring was put down here for water to a depth of 846 feet without success; the details may be grouped as follows:—Warp, 4 feet; Drift, 18 feet; Red Sandstone (Lower Mottled), 90 feet; Limestone and Clay bands, 147 feet 2½ inches; Hexthorpe Limestone, 210 feet; Sandstone shale and coal smut (Coal Measures), 376 feet 6 inches. The watershed separating the *DON* Basin

from that of the *TRENT* descends from 426 feet, on the Carboniferous rocks, south of Doncaster, to 45 feet, on the Pebble Beds of the New Red Series, north of that town, which the watershed approaches very closely. Rateable value, 78,916*l.*

Pickhill.—*Acres*, 489; population, 1915 (?); supply from springs, wells, and brooks traversing the village; rateable value, 3853*l.* 19*s.* 9*d.*

Sumpton.—*Acres*, 1700; population, 5150 (?); wells; rateable value, 30,673*l.*

Goole.—*Acres*, 1002; population, 10,339; no public supply at present, subject under consideration. The place is underlaid by New Red Sandstone, so there should be no difficulty in obtaining an underground water supply.

The direction of the course of the *DON*, like several other rivers on this side of England, is first south-eastward and then north-eastward, the change of course in this case being at Sheffield; the Manchester and Sheffield Railway follows the lines of its valley, and that of the *Etherow* on the western side of the central watershed. It flows from Thurlstone and Bradfield, receiving on its south bank the tributaries *Arden Water*, *Loxley*, and *Rivelin*, and immediately below Sheffield the *Sheaf*, falling in at 167 feet above the sea, up to which point the *DON* is navigable. The Chesterfield Railway follows the *Sheaf* valley for some distance, and then traverses the valley of the important tributary the *Rother*, which drains the long tongue of land extending from Alfreton, Claycross, Chesterfield (242 feet), to Sheffield and Rotherham. A canal commencing at Chesterfield at 239 feet, and crossing the *TRENT* watershed at about 250 feet, near *Hart Mill Pond*, (the source of the *Idle*), is carried by Worksop to the *TRENT*, immediately above Gainsborough, near the infall of the *Idle*.

Alfreton (Derbyshire).—*Acres*, 4578; population, 4492; no public supply; rateable value, 34,373*l.*

Clay Lane.—*Acres*, 1444; population, 6870; waterworks

constructed under an Act to supply Claycross and neighbourhood with water (1876), limits supply to 80,000 gallons, and this is intermittent; half is taken from the Woferly spring and half from *Peats brook*. The water is stored in a small reservoir and filtered.

CHESTERFIELD.—*Acres*, 328; population, 12,221; rateable value, 43,100*l*. Supply from Waterworks Co., Limited, who obtain it from upland gathering-ground of Millstone Grit, 1355 acres in extent, of which only 5 per cent. is arable, the rest pasture. There are two impounding reservoirs of 43 acres, holding 156,000,000 gallons; from these the water flows unfiltered to a service reservoir of 6,000,000 gallons; it is then distributed at the rate of 700,000 gallons daily in an area of about 18,000 acres. The Rivers Pollution Commission states it would be improved by efficient sand filtration. The total solid impurity was 15·80, and the hardness 10·3, of which 7·4 was permanent. Chlorine 1·25, Organic Carbon, 0·226. The *Company* supply the following:—Brampton and Walton, *acres*, 10,098; population, 7567; rateable value, 26,328*l*. 6*s*. Dronfield, *acres*, 965; population, 4331; supply intermittent; 11,000 gallons; rateable value, 13,721*l*. 18*s*. Whittington, *acres*, 1575; population, 7271; supply constant; rateable value, 22,082*l*. Newbold and Dunston, population, 6158; rateable value, 25,410*l*.

A little south of Handsworth the river leaves Derbyshire and enters Yorkshire, flowing for 3 or 4 miles north, until it falls into the *DON* at Rotherham.

HANDSWORTH.—*Acres*, 3638; population, 7644; no public supply; rateable value, 19,507*l*.

River Dearne.

The northern tributary, the *Dearne*, is 21 miles long; rising in the Carboniferous rocks north of Thurlstone, and flowing entirely over these rocks past Barnsley, falls into the *DON* just west of the outcrop of the Magnesian Limestone.

Barnsley.—*Acres*, 2385; population, 29,789; Corporation Waterworks obtain their supply from Ingbirchworth, 9 miles distant. The gathering-ground is 1750 acres in extent, the water is stored in a reservoir, and a constant supply of 1,000,000 gallons daily is given; rateable value, 80,430*l.* 0*s.* 5*d.* Works carried out under 25 & 26 Vict. c. 32, and 29 Vict. c. 98.

Barnsley Corporation Supply:—Darton, *acres* 4358; population, 6011; supply averages 20 gallons per house, at an average of 4½ persons to each house; rateable value, 17,690*l.* 17*s.* 1*d.*; Public Health Act, 1875. Dodworth, *acres*, 1801; population, 2989; constant supply; rateable value, 17,699*l.* 15*s.* 3*d.* Monkbretton, *acres*, 2918; population, 2090; supply constant of 1600 gallons per day at 1*s.* per 1000; rateable value, 16,435*l.*; Public Health Act, 1875. Hoyland Swaine, *acres*, 1917; population, 750; supply, supplemented by springs; 1000 gallons used; rateable value, 2757*l.* 12*s.* 6*d.* Worsbrough, *acres*, 3592; population, 8440; supply constant of 44,600 gallons; rateable value, 28,088; Public Health Act, 1875.

Local Authorities in the *Dearne* district not supplied by Barnsley:—Wombwell, *acres*, 3851; population, 8451; supply from reservoir in district of Hemingfield. Reservoir fed by drift and catchwater springs at Heming and private reservoir at Wombwell Main. The pumping station from the *Oaks Rock* proposed for the supply of Wakefield by their Act of 1876 was in this district, since abandoned by them for a site nearer home. From the evidence given on that Bill it appears that in sinking the collieries at the New Oaks, Darfield Main, Mitchell Main, Manvers Main, and Wath Main, through the *Oaks Rock*, an average of 3,685,000 gallons of water was met with, the maximum quantity pumped per day being 4,924,000 from New Manvers. An analysis of Wath water made by Dr. C. Meymott Tidy, of a sample obtained by Mr. Hawksley, C.E., gave a total hardness of 18·00, of which 3·40 was permanent, chlorine 4·40. A

pumping-station on this site, for the supply of the group of townships around Wombwell, has been suggested by Messrs. Mitchell and Peacock, of Barnsley. They gave the following table of population, in 1876 :—

	In 1871.	Estimated in 1881.	Actual in 1881.
Hoyland	6,298	10,000	—
Worsbrough	6,030	10,000	8440
Wombwell	5,014	8,000	8451
Darfield	1,673	3,000	2903
Wath .. .. Brampton-Bierlow, including West Melton	4,001	5,000	—
Mexborough	4,316	6,000	6271
Swinton	5,150	6,000	7611
Total	32,482	48,000	——

Wath-upon-Dearne. — *Acres*, 770; population, 2903; supply from reservoir of West Melton Waterworks Company, Limited (surface water from cultivated land), of 12 gallons per head; rateable value, 6055*l.* 2*s.* Rainfall in 1879, at 100 feet, 29·68 inches.

Mexborough.—*Acres*, 1070; population 6271; supply 30,000 gallons, from Mexborough and District Waterworks Company, who pump deep well; rateable value, 17,465*l.* 13*s.*; works under Companies Act, 1862-67.

River Went.

This river is 16 miles long, drains the deflection in the trend of the northern watershed of the *DON* before referred to, and flowing past Ackworth, 95 feet, Kirk Smeaton and Sykehouse, 17 feet, falls into the *DON* between Thorne and Goole.

Askern.—Population, 548; supply constant from well; rateable value, 3317*l.*

The eastern half of the course of this stream is over

permeable Magnesian Limestone, and Alluvium overlying Pebble beds.

Population in North-Eastern, and Central Humber Group of River-Basins.

In Census 1871.

County.	Population. (County.)	Density. Acres per Individual.	Proportion of Population in Humber Basin.	Population, about.
Yorkshire, N.R. ..	291,589	4·0	$\frac{9}{10}$	262,431
„ W.R. ..	1,831,223	0·9	$\frac{149}{150}$	1,819,015
„ E.R. ..	269,505	2·8	All	269,505
York (City)	43,796	—	All	43,796
Derbyshire	380,538	1·7	$\frac{1}{5}$	76,107
In Census 1881.				
Yorkshire, N.R. ..	346,147	3·9	$\frac{9}{10}$	311,533
„ W.R. ..	2,175,134	0·8	$\frac{149}{150}$	2,160,634
„ E.R. ..	310,830	2·0	All	310,830
York (City)	54,198	0·3	All	54,198
Derbyshire	461,141	1·4	$\frac{1}{5}$	92,228

CHAPTER VI.

BASIN OF THE HUMBER, SOUTHERN GROUP.

RIVER TRENT (*LXXII.*).

THIS river is 147 miles long, and drains with its tributaries 4052 square miles, of which the following table gives an analysis :—

Bank.	Charnwood Forest Rocks.	Carboniferous Limestone.	Carboniferous Rocks.	Magnesian Limestone.	Permian Limestone and Marls.	Triassic Sandstone.	New Red Marls.	Lias.	Oolites.	Total.
Left ..	..	450	304	174	32	600	750	..	..	2310
Right	10	10	172	..	76	229	812	421	12	1742
Total	10	460	476	174	108	829	1562	421	12	4052

Regarding the Yoredale and Millstone Grits and Coal Measures as impermeable, 2479 square miles consist of impermeable marls, clays, and shales, or nearly two-thirds of the entire area. The river rises on the eastern slope of the Pennine Chain, at about 500 feet; it descends to 382 at Stoke, 288 at Stone, 250 at Stafford, 158 at Burton-on-Trent, 42 at Newark, and falls into the tidal waters of the *HUMBER*.

The course of the *TRENT*, from its source in the Carboniferous rocks overlooking the plain of Crewe, is first southwards over the Coal Measures of Stoke and the Permians fringing the North Staffordshire Coalfield, then south-eastwards from Stone, where it passes on to the Keuper Marls, at 325 feet above the sea, by Rugeley, 240 feet above the sea,

where a small exposure of Lower Keuper Sandstone comes to the surface, to the point where the *Tame* falls in at 160 feet above the sea; here its direction abruptly changes to east-north-east, which continues as far as Newark, which taking the mean distance is nearly 50 miles distant. In the whole of this tract it flows over Keuper Marls, with here and there small tracts of Lower Keuper Sandstone, as at Melbourne, and Castle Donington, and Nottingham. It will be noticed that the country drained by the *TRENT* and its tributaries is a basin in the Palæozoic rocks filled in at the bottom by Triassic rocks, the various sub-divisions of which are rapidly thinning southwards, so that each member of the series overlaps southwards the rock beneath it. The northern portion of the basin from Nottingham to Hanley is a triangular shaped area, and contains about 700 square miles, consisting chiefly of Carboniferous Limestone; over it run the upper 13 miles of the course of the *Ilkeston* Brook, 57 miles of the *Derwent*, 5 miles of the *Dove*, and the sources of the *TRENT*.

Between the Palæozoic rocks of the Wrekin, flanked by the Coalbrookdale Coalfield and Permian, and the South Staffordshire Coalfield with its fringe of Permian, is a narrow trough filled in with Trias, through which flows the *Stour*, a tributary of the *SEVERN;* this trough at Kinfare is only 4 miles in width from coalfield to coalfield, and 3 miles between the margin of the Permian rocks. At this point the ground is 176 feet above the sea; the stream falls into the *SEVERN* at 59 feet, which at Iron Bridge, 22 miles to the north, has only attained an elevation of 133 feet at the Coal Measures flanking the Wrekin. Drawing a line of section from this point across the Triassic rocks occupying the country between Iron Bridge and Nottingham, it passes at the foot of the northern termination of the South Staffordshire and Leicestershire Coalfields, and coincides in direction with the present course of the *TRENT*, from the infall of the *Tame* to Nottingham and Newark; continuing the line, it enters

the Lias, and crosses the *Witham* and *TRENT* watershed, near Scarle, where a boring has been carried down through the Secondary and Newer Palæozoic rocks to the Coal Measures, passes over the oolites at Lincoln, and re-enters the *HUMBER* Basin, and reaches the sea at Donna Nook. At the Iron Bridge end of this section the base of the Trias and Permian rests upon the Carboniferous rocks at 133 feet, following the valley of the *SEVERN* up stream, the base of the Trias and Permian steadily rises to 200 feet at Shrewsbury, and 380 feet on the watershed between the *SEVERN* and the *DEE*, north of which it descends along the border of the Flint Coalfield. The existing east and west watershed, running through Ellesmere, Whitchurch and Drayton, and Newcastle-under-Lyme, being superimposed on a still more ancient ridge of Palæozoic rocks, the eastern prolongation of which beyond the Pennine watershed is marked by the Triassic conglomerates, resting on the Carboniferous rocks between Newcastle-under-Lyme and Ilkeston. Rainfall percolating into the Trias lying south of the *DEE* and *SEVERN* watershed and north of the Trias of the *TRENT* valley will flow south, and it is important to ascertain whether any water received in the *SEVERN* Basin will flow into the *TRENT* Basin, or any of the underground supplies of the latter percolate into that of the *THAMES*.

The *SEVERN* flows at or near the western margin of the Trias, the base of which descends from 133 feet at Iron Bridge to 59 feet south of Bewdley, in a distance of 20 miles, or 4 feet per mile traversed. Continuing this line of direction through Tewkesbury into the valley of the *THAMES* to the Burford boring, the surface of the oolites is 300 feet above the sea, and the Palæozoic floor 884 feet beneath it. The distance from the Palæozoic rocks south of Bewdley is 48 miles, which at a dip of 4 feet per mile, would give 192 feet, or a depth to the Palæozoics below the level of the sea of 133 feet, instead of 884 feet, the actual depth ascertained, proving a considerable depression under the *THAMES* Basin of older

date than the Secondary rocks, which continues eastwards, the floor of the Palæozoics under London being 1000 feet beneath the sea-level. The base of the Lias at Tewkesbury is 40 feet above the sea, in the Burford boring it is 356 feet below it, giving an average dip of 14 feet per mile, so that the underground drainage of the country lying between the mouth of the *SEVERN* and Kinfare must pass into the *THAMES* Basin, so far as it consists of porous Trias, but the greater part is occupied by impermeable Keuper Marls throwing off rainfall as floods.

The *SEVERN* and *TRENT* watershed between the North and South Staffordshire Coalfields traverses the Trias. The watershed between Newport and Stafford is 341 feet above the sea, or more than 231 feet above the base of the Trias and Permian at Iron Bridge. Forty-three miles to the east-north-east, at Melbourne, the Leicestershire Coalfield forms the surface, and the *TRENT* flows over the Keuper Marls lying at its foot, at a level of 150 feet above the sea. The Marls here are probably only underlaid by the Lower Keuper Sandstone, and the Palæozoic floor, at its lowest point between Melbourne and Derby, will be at a little below the mean level of the sea, giving 133 feet fall in 43 miles, or a fall of 3 feet per mile; this gradient continued to Scarle, 37 miles further, would give a depth of 111 feet below sea-level to the older Palæozoics, instead of 1900 feet as actually found, proving that the gradient increases suddenly between the two points, probably east of a line connecting the Coal Measures of Nottingham with the Charnwood Forest rocks, beneath Castle Donington. The sectional area of New Red, measured from the Palæozoics on the north and those on the south, is about 12 miles, and through this gorge passes the underground drainage of the Permian and Trias of the greater part of the *TRENT* above Castle Donington, and of part of the upper *SEVERN* above Iron Bridge and Shiffnal; in fact, were the Trias to be excavated out by denudation, the drainage of the *SEVERN* would not as now pass between the

Wrekin and Wenlock Edge, but eastward by Newport and Stafford into the *TRENT*. The district thus brought into contribution to the *TRENT*, but draining superficially into the *SEVERN*, is about 450 square miles of Triassic and Permian rocks.

The southern portion of the *TRENT* Basin, lying between the South Staffordshire and Warwickshire Coalfield, and between the latter and Ashby-de-la-Zouch Coalfield and the Charnwood Forest rocks, has an underground drainage into the *THAMES* Basin; a line drawn from Mount Sorrel, through Tamworth, the South Staffordshire Coalfield, at Walsall, the *SEVERN* triassic gorge, at Kinfare, probably marking the limits of subterranean water-parting.

At Newtown Chitbank, near Desford, east of Market Bosworth, the surface is 320 feet above the sea-level, and the Coal Measures beneath the Keuper Marls and Waterstones 58 feet above it; further north, at Lindridge Colliery, in the same district, 270 feet were penetrated without the base of the Waterstones being reached, the bottom of the borehole being 130 feet above the sea. Further south, at Elmsthorpe, 300 feet above the sea, a boring was carried to a depth of 1400 feet, the top of the Coal Measures being 160 feet beneath the mean sea-level, proving a southerly gradient towards the *THAMES* Basin.

In the basin of the *TRENT* the correspondence in the direction of the strike or *outcrop* of the Triassic and Permian rocks on the Palæozoic rocks, whether it be the great mass extending from Burslem to Nottingham, and northwards to Doncaster and the far north, or the smaller masses formed by Charnwood Forest and the Midland Coalfields, is very marked, and points to these tracts having been land rising above the level of the water in which the Bunter conglomerates were deposited. Thus the north and south strike of the Trias between Doncaster and Nottingham turns abruptly westwards at that town with the margin of the Carboniferous rocks by Derby, Cheadle, and Stone. Passing out of the

TRENT Basin a like parallelism is seen fringing the Welsh and Shropshire Palæozoics between Worcester and Newport, Shrewsbury and Chester, and again in the Central Carboniferous region between Macclesfield and Manchester.

The *Left Bank* of the *TRENT* to Nottingham consists of Permian Marls, Magnesian Limestone, Lower Mottled Sandstone, Pebble Beds, Waterstones, and Keuper Marls; the middle four are permeable, and occupy about 654 square miles; the impermeable marls extend over 310. The tributaries draining this area chiefly run on the base of the Magnesian Limestone, immediately above and parallel to the watershed of the *DON*, at heights of from 200 to 250 feet; the water absorbed by these rocks will be carried down eastward under the Keuper Marls forming the bed of the *TRENT*, and the Lias and Oolites of the *WITHAM* Basin around Lincoln, and of the *ANCHOLME* Basin, between Brigg and Market Rasen, and still further east, under the cretaceous rocks of the Lincolnshire Wold.

Crowle and Keadby are situated on the alluvial Warp of the *HUMBER*, and are well situated for deep borings for water into the Lower Trias. Through this alluvial tract runs the course of the *Old Don*, and a canal connects the basin with that of the *DON* at Thorne.

The *Tarne* is 22 miles in length, rising at the base of the Magnesian Limestone close to the low watershed of the *DON* basin, at a point very close to that river. On the *Tarne* are Cantley, Wadsworth, Pick Hill, 53 feet.

Rivers Miden and *Idle*, length 42 miles. The *Idle* proper rises at the base of the Magnesian Limestone south-east of Rotherham, which it flows over to Worksop, reaching the Lower Mottled Sandstone at about 120 feet above the sea, thence it turns northwards and flows nearly with the strike over the Pebble Beds. The *Miden* and its tributaries the *Poulter*, the *Maun*, 13 miles long, and a stream rising south of Mansfield, run a similar course, and drain entirely a permeable area, and flow in the main in the direction of the

strike of the rocks. In this area are Ollerton, Mansfield, Sutton-in-Ashfield, Warsop, and Shinbrook.

West Retford.—*Acres*, 930; population, 690 (?); wells; rateable value, 645*l.* 8*s.* 2*d.*

Worksop.—*Acres*, 18,220; population, 11,625; Waterworks Company formed in 1875, well, and reservoir; rateable value, 66,479*l.* Rainfall in 1879, at 127 feet above the sea-level, 27·29 inches.

Warsop.—*Acres*, 5991; population, 1329; the river *Miden* traverses the district, wells; rateable value, 751*l.*

Sutton-in-Ashfield.—Population, 8523; wells; rateable value, 16,955*l.* 3*s.*

Mansfield Woodhouse.—*Acres*, 4060; population, 2617; wells; rateable value, 848*l.* 11*s.*

Mansfield.—*Acres*, 9070; population, 13,651; wells; *Mansfield Waterworks Company* established in 1870; supply constant 90,000 gallons; rateable value, 35,275*l.* Rainfall in 1879, 29·70, at 350 feet above Ordnance Datum.

East Retford (Notts).—*Acres*, 130; population, 9748; from wells by means of pumps; rateable value, 10,087*l.* 8*s.* 11*d.*; the Corporation are promoting a Bill for the extension of the borough.

Of well waters from Yorkshire and Nottingham Magnesian Limestones, the Rivers Pollution Commissioners give the following analysis:—

	Pontefract, Yorkshire.	Mansfield, Well, 75 feet deep, Waterworks.	Mansfield, Mr. Peat's Well.
Total solid impurity	84·92	25·24	54·32
Organic carbon	·054	·053	·139
Organic nitrogen	·021	·014	·039
Ammonia	0	0	0
Nitrogen as nitrates and nitrites	2·673	·599	1·888
Total combined nitrogen	2·694	·613	1·227
Previous sewerage contamination	26·410	5·670	11·560
Chlorine	5·55	1·40	3·20
Hardness — Temporary	26·5	6·0	23·4
Hardness — Permanent	40·8	16·4	26·0
Hardness — Total	67·3	22·4	49·4

NOTTINGHAM.—*Acres*, 9958; population, 186,656. The public water supply of Nottingham is chiefly from two sources, the Basford and Bestwood wells. These wells, sunk in the New Red Sandstone rock, are situate at a distance from the town, and yield an average supply of 2,719,000 gallons per diem. This water is of very good character. The remainder of the 3,069,000 gallons supplied daily from the Company's sources comes partly from the Scottholme springs (70,000) in the Leen valley, and partly from Park well (280,000), sunk in the sandstone rock in a thickly populated part of the town. The former source was strongly condemned some years ago, although it has been in use until lately, and there is no security against its being used again. In addition to the above-mentioned supply, there are a good many private wells, chiefly in the Magnesian Limestone, at the northern extremity of the borough. The water from these sources is invariably found on analysis to be exceedingly hard, and in some cases largely polluted with sewage. These wells are being closed. Reservoirs; 20 gallons per head, of which one-third is taken by trade (c.); rateable value, 600,000*l.*

The Bagthorpe well is 120 feet deep, and yielded in 1871 above 3,000,000 gallons; the Rivers Pollution Commission state its water "to be of most excellent quality for dietetic purposes—clear, sparkling, palatable, and wholesome." Its total solid impurity was 24·80; hardness, 21·4, of which 1·10 are permanent; chlorine, 1·80. The private wells were of a depth of 200 feet, and the water contaminated. The well at the Bestwood Park pumping station was sunk at the suggestion of Mr. M. D. Tarbotton, borough engineer. The shaft is 192 feet deep, size 16 feet × 10 feet; two tunnels are driven out from the bottom about 50 yards. The works are all in the Pebble Beds of the New Red Sandstone; the maximum quantity pumped in 1875 was 3,772,800 gallons, and the minimum 316,800 gallons less. The quantity now must be much reduced, as the two wells only yield 2,719,000 gallons, or an average of 1,359,500 gallons per well.

The Bunter Pebble Beds of Bulwell Forest, near Nottingham, throw out a copious spring of magnificent water—clear, brilliant, and wholesome, which might be drawn upon for a supplementary supply if the deep well should fail to yield an adequate quantity. The total solid impurity was 21·96; organic nitrogen, 0; total hardness, 11·9, of which 11·0 was permanent.

RAINFALL in 1880 at HIGHFIELD HOUSE OBSERVATORY, near NOTTINGHAM.—(E. J. LOWE, F.R.S.)

Gauge:—Above ground, 12 in.; above sea-level, 164 ft.

	Inches.	In 24 hours.	Date.	Days when more than 0·1 fell.	Fall in 1879.	Fall in 1878.
January	0·530	0·181	16	8	1·6	2·0
February	2·154	0·742	17	19	3·0	1·1
March	1·721	0·808	3	7	1·0	0·6
April	2·091	0·803	5	15	2·6	1·3
May	1·765	0·732	27	7	3·6	4·4
June	5·800	1·249	23	20	4·5	2·7
July	6·567	1·303	27	21	3·7	2·6
August	3·063	1·061	20	9	4·4	8·8
September	4·304	1·326	13	15	3·3	1·5
October	4·856	1·500	5	17	1·3	3·1
November	2·086	0·787	14	15	1·5	2·4
December	3·178	0·685	15	21	1·2	2·5
Total	38·115	11·177	..	174	31·7	33·0

Rainfall of the last 41 Years.

	Greatest Rainfall.	Year.	Average.	1880 Above or Below Mean.
January	3·6	1877	2·0	1·470†
February	3·6	1848	1·5	·645*
March	3·9	1848	1·6	·121*
April	4·3	1846	1·8	·291*
May	5·0	1847	2·3	·535†
June	5·8	1880	2·5	3·300*
July	7·4	1872	2·4	4·167*
August	8·8	1878	3·0	·063†
September	5·6	1852	2·6	1·703*
October	5·4	1875	2·7	2·156*
November	7·0	1852	2·3	·264†
December	6·6	1868	2·0	1·178*
Total	..	..	26·7	11·415*

* Above average. † Below average.

		Inches.
Average quarterly fall ..	February, March, and April ..	4·9
	May, June, and July	7·2
	August, September, and October ..	8·3
	November, December, and January	6·3
Largest daily rainfall ..	1857 .. August 13	3·010
	1878 .. August 6	2·516
	1878 .. July 24	2·215
	1865 .. August 24	2·163
	1869 .. September 19	2·136
	1875 .. August 7	2·104
	1852 .. July 26	2·063
	1852 .. September 6	2·044
Largest monthly rainfall	1878 .. July 24 to August 24 ..	9·4
	1875 .. June 28 to July 27	7·7
	1857 .. August 6 to September 6	7·7
	1852 .. October 29 to November 29	7·6
	1875 .. July 14 to August 14 ..	7·5
	1880 .. June 19 to July 19	7·1
	1880 .. July 9 to August 9 ..	7·1
Largest quarterly rainfall	1875 .. 3rd quarter	14·2
	1880 .. „	14·0
Largest half-yearly rainfall	1880 .. May to October	26·5

Nottingham Waterworks Company supply Arnold, *acres*, 4670; population, 4634; rateable value, 13,384*l.* 6*s.*

The *left* bank of the *TRENT* above Nottingham consists of Carboniferous Limestone, 450 square miles; Carboniferous rocks, 304; Permian Sandstone, 32; New Red Sandstone, 100; Marls, 440. Of this area of 1326 square miles, with the exception of the Keuper Marls, the whole of the rocks are more or less permeable. Considering two-thirds of the Carboniferous rocks as impermeable, half the area is incapable of receiving any percolation from rainfall.

The *Ilkeston* stream rises immediately south of the *DON* watershed in the Magnesian Limestone, but, unlike the stream already described, flows west and south over the Carboniferous rocks lying between Alfreton and Ilkeston, south of which it passes over a narrow tract of Pebble Beds, and then, crossing the Keuper Marls, it falls into the *TRENT* between Castle Donington and Nottingham.

ILKESTON.—*Acres*, 2541; population, 14,119; 82,700 gallons, partly pumped from shaft and partly collected in a storage reservoir from a gathering-ground; new service reservoir,

shaft, and filtering grounds are required; rateable value, 31,008*l.* 18*s.*

Hucknall-Torkard.—Population, 10,023; brooks and wells only; rateable value, 24,357*l.*

Hucknall-Huthwaite.—*Acres*, 1160; population, 2033; supply from artesian well; rateable value, 3997*l.*; water-works required.

Heanor.—*Acres*, 1570; population, 6823; constant supply of 15,000 gallons from shafts; works in progress to yield 250,000 gallons; rateable value, 19,543*l.*; Public Health Act, 1848; Local Government Board Acts, 1858, 1875.

Beeston.—Population, 4479; partly from wells and partly from *Nottingham Water Company;* rateable value, 11,000*l.*

River Derwent.

This stream is 54 miles long, rises north-east of the Peak in Derbyshire. Chief places, Belper (Alfreton), Winster, Castleton, Derwent Chapel, about 600 feet.

Alvaston and Boulton—*Acres*, 2098; population, 1507; wells; rateable value, 7138*l.*

Derby is situated on the New Red Marl plain at the foot of the Carboniferous escarpment, 166 feet above the sea.—*Acres*, 3445; population, in 1881, 80,410. Derby Water-works Company give constant supply of 2,000,000 gallons from springs and filter-tunnels, in a water-bearing bed of sand and gravel, under the Derby Waterworks Act; rateable value, 250,000*l.* Rainfall at Christ Church Vicarage, 265 feet above Ordnance Datum, in 1879, 31·98 inches.

Belper.—*Acres*, 2852; population, 9875; two reservoirs storing springs give a constant supply; under Belper Water-works Company's Act, 1860; rateable value, 26,952*l.* Rainfall at 355 feet above O.D., in 1879, 35·83 inches.

Wirksworth.—*Acres*, 2904; population, 3678; reservoir gives 72,000 to 144,000 gallons supply, from springs in the Millstone Grit; works under the Wirksworth Enclosure Act, 43 Geo. III. c. 42, in the year 1802; rateable value, 11,807*l.* 7*s.* 2*d.* Rainfall in 1879, at Holloway, 500 feet above the sea, 38·97 inches.

Between Belper and Wirksworth the *Derwent* receives on its east bank the *Amber*, rising near Ashover, and flowing over Carboniferous rocks by Alfreton.

Ripley.—*Acres*, 1212; population, 6081; supply, 100,000 gallons from water tower, tank, and well 60 yards deep; rateable value, 16,730*l*.

Returning to the *Derwent* towns:—

Bonsall.—*Acres*, 2387; population, 1354; supply from springs; rateable value, 3250*l*.

Matlock.—Population, 4396; reservoir storing springs, in the parish of Darley, giving constant supply, except in drought; rateable value, 17,000*l*.; the works are carried out under the *Matlock Waterworks* (*Company*) Act, 1860. The Company also supply Matlock Bath and Scarthin Nick. —*Acres*, 300; population, 1698; rateable value, 6006*l*. The water has not been analyzed by the Rivers Pollution Commission. Rainfall in 1879, at 500 feet above the sea, 39·10.

Heage.—Population, 2405; supply from public wells; rateable value, 7389*l*.

North Darley.—*Acres*, 4942; population, 1848; from springs in the hill-side; rateable value, 9216*l*. 16*s*. 8*d*. South Darley.—*Acres*, 1963; population, 605; wells and springs; rateable value, 3430*l*.

Long Eaton.—*Acres*, 2000; population, 5542; private wells; rateable value, 20,000*l*.

Immediately north of Darley the *Derwent* receives on its west bank the *Wye*, into which falls the River *Lathkill*, draining the district round Youlgreave and Winster at a point close to the *Derwent*. Leaving Darley and Stanton, the *Derwent* flows by Beeley, through Chatsworth Park, Baslow, Eyam, Hathersage, and Derwent Chapel, parallel to the *DON* watershed, 3 or 4 miles to the eastward, on the other side of which rises the headwater of the *Rivelin*, flowing down to Sheffield.

The sources of the *Derwent* are the *Wrangsley* and the *Alport*, which unite immediately south of Derwent Chapel; the *Alport*, and its tributary the *Ashop*, drain the northern

slope of the Peak country; while the southern slope, looking towards Castleton, is drained by another tributary of the *Derwent*, the River *Nor*, rising in the Peak, flowing by Edale Chapel and Hope, and falling into the *Derwent* west of Hathersage.

River Wye.

This tributary of the *Derwent* is 11 miles in length; it rises near the summit of the Pennine watershed, overlooking the source of the *Goyt*, between the Peak, 1981 feet above the sea, and Axe Edge Hill, 1751 feet; it flows past Buxton, south-eastwards to the *Derwent* at Rowsley. Buxton, *acres*, 1147; population, 6021 (more in the season); supply from springs on the side of Coombs Moor and on the Burbage side from Axe Edge, stored in a reservoir; rateable value, 26,393*l.*; Local Government Act, 1858; Buxton Local Act, 1873. Fairfield, *acres*, 3900; population, 1464; supply constant from Waterswallow reservoir, another in course of construction at Blake Edge; rateable value, 4000*l.*; under Fairfield Local Board Waterworks Act, 1874. Bakewell, *acres*, 2623; population, 2502; reservoir gives 50,000 to 90,000 gallons; storing springs in Millstone Grit; rateable value, 11,345*l.*; Public Health Act. Baslow and Bubnell, *acres*, 5465; population, 843; supply of part of district from private reservoir annually paid for; rateable value, 3911*l.*

River Dove.

Following the left bank of the *TRENT* westwards from the point where it receives the *Derwent*, at a level of 103 feet above the sea, it flows past Chellaston and Egginton to the infall of the *Dove;* this stream is 29 miles long; like the *Wye* and the *Derwent*, it rises near the summit of the Pennine watershed, on the eastern slope of Axe Edge, near Longnor; thence it flows south-east by Hartington, Tissington, near which it receives, on its western bank, the *Manyfold*, 11 miles in length, rising near Butterton, with its sub-tributary the River *Hamps*, rising near Grindon. At Ashborne the

course of the *Dove* changes to south-south-west, by Norbury and Bicester to Uttoxeter, whence it flows nearly east, by Tutbury, to the *TRENT*. For a couple of miles at Ashborne the river, on leaving the Carboniferous rocks, passes over the Pebble Beds and Lower Keuper Sandstone, and then traverses the Keuper Marls to its outfall.

ASHBORNE.—Population, 3485; wells private and public; rateable value, 9633*l*.

River Churnet.

This tributary of the *Dove* is 23 miles long, rises on the summit of the Pennine chain, north of Meerbrook and Leek; at the latter place it traverses an inlier of the Triassic Pebble Beds resting on the Yoredale rocks. At Cheadle it passes over a narrow belt of Pebble Beds and Lower Keuper Sandstone, and then traverses the Red Marls to the *Dove* between Uttoxeter and Ashborne.

LEEK.—*Acres*, 1460; population, 12,865; springs that also supply a water corn-mill are impounded in a small reservoir holding half a day's supply; 350,000 gallons are taken; if not all used, the surplus flows into the *Churnet;* rateable value, 30,426*l*.; works carried out under Leek Improvement Act, 1835; the purchase of the mill is desirable. Rainfall 34·13 in 1879, at 538 feet above the sea.

A canal follows the line of the *Churnet*, starting at 301 feet above the sea, at Uttoxeter, it rises to 375 feet at Cheadle, and, crossing the minor watershed at 495 feet, passes into the valley of the Upper *TRENT*, descending to 454 at Hanley, and joins the *TRENT* Canal at Stoke, 370 feet above the sea.

Following the left bank of the *TRENT* from the infall of the *Dove* to its source, it flows south-west past Burton-on-Trent, up to which town it is navigable, to a point opposite the infall of the *Tame*, thence it trends north-westwards by Stone, Stoke, and Hanley, to its source on the Pennine watershed, overlooking the sources of the *Dane*. The canal that follows the north bank of the *TRENT*, from the infall of the *Derwent*,

at 103 feet, rises to 156 feet where it crosses the *Dove*, and to 166 feet where it crosses the *TRENT*, and passes to the right bank of the stream, rising to 240 feet at Rugeley, again crossing to the left bank opposite the infall of the River *Penk* at 252 feet, it rises to 325 feet at Stone, 376 feet at Stoke, crosses the Pennine watershed into the basin of the *Wheelock* at 420 feet, at the same point that it is crossed by the North Staffordshire Railway.

STONE.—*Acres*, 500; population, in 1881, 5669; no public supply; rateable value, 11,667*l.* 2*s.* 6*d.*

The *River Blythe* (tributary of the *TRENT*) rises between Stone and Uttoxeter, and entirely drains a Red Marl country; its course is nearly parallel to the *TRENT* and *Dove;* between it and the *TRENT* is Hopton Heath, and between it and the *Dove* occur several outliers of Lias, near Bagots Park, between which and the river is Abbots Bromley. Between the infall of the *Blythe* and that of the *Dove* no town of importance occurs on the left bank, except BURTON-ON-TRENT, *acres*, 1510; population, 39,285; a constant supply of 500,000 gallons is given by the *South Staffordshire Waterworks Company;* rateable value, 120,000*l.* Rainfall at the Grammar School in 1879, 160 feet above the sea, 28·96.

The presence of sulphate of lime in the water used in brewing at Burton-on-Trent, by Messrs. Bass, Allsopp, Salt, and other firms, is believed to give the Burton water its special pre-eminence in the manufacture of beer. Mr. Molyneux believes the large amount of calcareous ingredients here met with (70 grains in an imperial gallon) to be due to the water dissolving all the gypsum of the Keuper Marls of Needwood Forest, from whence it flows down the dip of the strata to the Burton Valley fault, up which it rises, and is tapped by the artesian borings of the breweries.

Herr Griess, F.R.S., informs Mr. Molyneux that the gypsum derived from the water used in brewing 1000 barrels of ale would be 250 lbs.; so that assuming Burton produces annually 1,400,000 barrels of ale, no less than 350,000 lbs. of this mineral will be drunk with the beer in various parts

of the world. Of the water derived from the Burton Valley Gravels, and used in various operations of brewing, probably not less than 1,050,000 lbs. of gypsum will be disposed of, which Mr. Molyneux considers will not represent one-tenth of the actual amount of gypsum being annually carried to the sea, and it is very probable that many local subsidences which have taken place in various parts of Needwood Forest are due to the fracture and sinking of gypsum beds eroded by underground streams.

The water recently obtained by several of the large brewing firms from the Keuper Sandstone and Bunter beds rose 23 feet above the level of the valley, proving the great height of the sources of supply. These waters were softer than those from the Marls or from the Valley Gravels, the proportion of sulphate of lime being much less.

The large number of journals of borings placed at Mr. Molyneux's disposal by Messrs. Allsopp and Sons, and Messrs. Salt and Co., have enabled him to establish the following sequence of deposits in the valley of the *TRENT*, in descending order:

1.	Old alluvial deposits	In the bottom of the valley.
2.	Valley sands and gravels	
3.	Terrace gravels	On the slopes of the valley.
4.	Stratified sands, gravels, and peat of fluviatile origin	
5.	Drift sands and gravel	On the top of the hills.
6.	Boulder clay	
7.	Rhætic beds	
8.	Keuper marls	1000 feet thick.
9.	Keuper sandstone	250 „
10.	Bunter conglomerate	300 „
11.	Coal measures.	

All the Burton wells, previous to 1856, were sunk in the Valley Gravels, and were not more than 20 feet deep. In that year Messrs. Ind, Coope, and Co. sank a well 24 feet in depth in Station Street, and since then all the old brewery wells have been deepened, and new ones carried down to the underlying Keuper beds.

To obtain a supplementary supply to that afforded by the gravels and the top of the Keuper deposits, Messrs. Bass and Co. bored through 194 feet of gypseous marls with bands of hard Sandstone, but it only produced one gallon of water per hour.

In 1867–8, Messrs. Allsopp and Sons sank 28 feet through gravels, and bored 102 feet with similar unsuccess. The various borings carried out by these firms and Messrs. Salt and Co. prove the existence of two faults in the very centre of the valley, bringing up the Keuper Sandstone with a vertical downthrow towards the river of no less than 1100 feet, the whole of which enormous mass of strata has been denuded away.

Mr. Molyneux gives the three following analyses of (1) water from artesian boring in Keuper Marls, 70 feet in depth, of (2) water from a well 30 feet deep in valley-gravels, on the east side of High Street, in the lime of the old breweries, and (3) of a well on the west side of that street:

	No. 1.	No. 2.	No. 3.
	Grains in an Imp. Gall.	Grains per Gallon.	Grains per Gallon.
Sulphate of Lime	70·994	25·480	7·050
Carbonate of Lime	9·046	18·060	15·526
„ Magnesia	5·880	9·100	2·128
Sulphate of Magnesia	12·600	0·000	0·000
„ Soda	13·300	7·630	3·689
Chloride of Sodium	9·170	10·010	6·636
„ Potassium	·966	2·275	13·447
„ Magnesium	·000	0·000	7·350
Carbonate of Protoxide of Iron	1·218	·900	Trace.
„ Manganese	..	..	Trace.
Nitric Acid (as Lime Salt)	..	..	Trace.
Silica	1·120	·840	1·904
Total Solid residue	124·294	74·295	57·730

All the borings prove the Keuper Marls to be non-water-bearing at Burton, the water found coming from the sandstone beneath them, with the exception of the wells in the Marls at Horninglow.

Mr. Robert Sutcliff, in a paper describing "Tube Wells

for Large Water Supplies" ('Trans. Soc. Engineers,' 1878), says that at Messrs. Allsopp's Brewery 3″ tubes well will yield 1500 to 2000 gallons per hour. With portable steam-pump he filled a cask containing 100 gallons in one minute, from a tube well 3 inches in diameter, in gravel 30 feet deep. With increased borehole the yield of water is not increased, but several holes, 10 to 30 being coupled together at Messrs. Allsopp and Sons' at Burton, yield 60,000 gallons per hour, or 600,000 gallons per day. Messrs. Bass and Co. have 25 coupled wells, from which they obtain 500,000 gallons daily.

Right bank of the *TRENT*.—Of the 1742 square miles of country draining in the river on this bank, only about 300 consist of permeable rocks, while half the area is occupied by the Keuper Marls, which largely overlie the Palæozoic rocks, without the intervention of the permeable Triassic Sandstones, which have thinned out southwards; so that in this area not less than five-sixths of the rainfall, left after evaporation, may be expected to flow off in floods.

Of the Red Marl area 154 square miles, situated between the South Staffordshire and Warwickshire Coalfield, probably overlie Lower Keuper Sandstone draining underground into the basin of the *Avon*, and eventually crossing that basin passes into the basin of the Upper *THAMES*.

In the Red Marl area between the Warwickshire Coalfield and Charnwood Forest, 236 square miles in extent, the New Red Sandstone is often absent, but when present the underground drainage is probably into the basin of the Bedford *OUSE*, and then into the *THAMES*.

West Midland Counties:—*Staffordshire* (North) *Potteries Waterworks Company* supply about twelve Local Sanitary Authorities under the Acts of Parliament 10 Vict. c. 17; 10 & 11 Vict. c. 204; 12 & 13 Vict. c. 36; 16 & 17 Vict. c. 198; 24 & 25 Vict. c. 146; 26 & 27 Vict. c. 93, and 31 & 32 Vict. c. 131. The water is pumped from the wells at Wall Grange Springs, near Leek, into Laddbridge

reservoir, and at the *Mere* near Longton. The water is stored in reservoirs at Hadyard, near Leek. The softness of it causes confervæ to grow on the surface of the water in the reservoir on exposure to the light.

The works at Longton consist of three wells, and two headings or tunnels intersecting each other in the form of a Greek cross. The longer limb of the cross runs east and west parallel with the railway, the shorter limb north and south. Commencing at the railway, it runs 198 feet to No. 2 well situated at the junction of the cross, with a 12 inch borehole 54 feet below the level; from this well to the extremity of the south heading is 39 feet. At the end is No. 1 well, 12 feet diameter, and 135 feet deep. The western heading is driven 213 feet, and a large quantity of water was obtained from it; it crossed a fault also met with in the southern level. The eastern level was driven 510 feet, and intersects a band of very hard stone and marl. In the latter, on the north side of the level, is sunk well No. 3, made for ventilation purposes. The yield is above 600,000 gallons a day, a new borehole in No. 3 giving an additional 380,000 gallons.

The *Potteries Works* supply the following Local Authorities:—Dresden, *acres*, 26; population, 3094; rateable value, 4422*l.* 9*s.* Smallthorne, population, 4614; supply constant; rateable value, 6181*l.* East Vale, *acres*, 20; population, 1419; supply constant; rateable value, 2747*l.* Newcastle-under-Lyme, *acres*, 630; population, 17,506; constant; rateable value, 38,700*l.* Burslem, *acres*, 2338; population, 26,521; constant, except on Wednesdays; rateable value, 68,291*l.* Kidsgrove, *acres*, 900; population, 3994; supply two hours a day; rateable value, 11,212*l.* 18*s.* 6*d.* Tunstall, population, 14,244; constant; rateable value, about 33,000*l.* Fenton, *acres*, 13,830; population, 10,000; nearly constant; rateable value, 33,740*l.* Hanley, *acres*, 1478; population, 48,354; intermittent; rateable value, 144,919*l.* 1*s.* 4*d.* Longton, *acres*, 960; population, 18,615; intermittent; rateable value, 60,708*l.* 9*s.* 10*d.* Stoke-upon-Trent, *acres*,

1660; population, 16,000; quality bad; rateable value, 58,400*l.*

No tributaries of importance fall into the right bank of the *TRENT* from its source to the infall of the *Penketh*. The stream and its affluents rise near the summit of the *TRENT* and *SEVERN* watershed; the district drained to the north consists almost entirely of Red Marls, and is traversed by the River *Sow* and *Mease* Brook, which fall into the *Penketh* near Stafford. The latter rises near Wolverhampton, near the point where the Kidderminster Canal crosses the *SEVERN* watershed, at 352 feet, and flows north by Brewood and Penkridge, over the New Red Sandstone, to the *TRENT* east of Stafford.

STAFFORD.—*Acres*, 1130; population, 19,982; ordinary wells. The Corporation are sinking a well, which has unfortunately intercepted a salt-bed, mains for supply are being laid in the street; rateable value, 49,330*l.*

The eastern registration district of Wolverhampton contains a population of 38,586, chiefly living in the *TRENT* Basin. The town of Wolverhampton is situated within the *SEVERN* Basin, and is described under that head.

River Pank (tributary of *TRENT*).

The following Urban Sanitary Authorities are supplied by the *Wolverhampton Corporation Waterworks*, who obtain their water from deep wells at Tettenhall and Goldthorn Hill, and the River *Worf*, a tributary of the *SEVERN*, in the county of Salop, which is subsequently filtered and strained through a wire gauze; one artesian well is 918 feet deep, half the depth is 24 inches diameter, and half 15½; the other is 300 feet deep and 7 inches diameter; there are also two ordinary wells. The hardness of the water in the Tettenhall reservoir was 16·9, in the *Worf* 21·5; the district is cultivated; of the Tettenhall well 28·8, of the Goldthorn Hill well 29·7, of the artesian well 21·5, of which 11·8 was permanent. Rainfall at Wrothesley, 500 feet above the sea, in 1879, 31·26 inches. The works were constructed originally by a private company, and were taken over by the Corporation under the

Wolverhampton Improvement Act, 1869, at a cost of 212,000*l.* The total supply is 2,000,000 daily, or 17½ gallons per head. The wells, as well as the pumping station, are situated in the *SEVERN* Basin.

Bilston.—*Acres*, 2580; population, 22,730; supply delivered at Bilston Market Cross of 220,000 gallons a day, intermittent; rateable value, 55,357*l.* 10*s.*; under Bilston Improvement Act, 1850.

Heath Town.—*Acres*, 138; population, 6244; supply constant; rateable value, 10,138*l.* 5*s.*

Short Heath.—Population, 2394; supply intermittent; rateable value, 5115*l.* 11*s.* 8*d.*

Wednesfield.—*Acres*, 2800; population, 4555; constant supply to village, and to New Invention; much of the district is agricultural and supplied by wells; rateable value, 14,426*l.*

Willenhall.—Population, 16,067; supply intermittent; rateable value, 32,282*l.* 12*s.* 3*d.*

Between Penkridge and Rugeley the *TRENT* flows past an extensive area of Pebble Beds of the New Red, and the North Staffordshire Coalfield, immediately bordering the valley, is a narrow belt of Lower Keuper Sandstone.

Rugeley.—*Acres*, 600; population, 4249; supply, private wells; the *South Staffordshire Waterworks Company* have obtained a Bill for its supply from works in Cannock Chase; rateable value, 9171*l.*

Cannock.—*Acres*, 8019; population, 17,127; partly from springs belonging to the Cannock Conduit Trustees, also by the *South Staffordshire Waterworks Company*, and 5 public wells.

River Tame.

This stream is 29 miles in length, rising on the southern extremity of the South Staffordshire Coalfield, between Halesowen and King's Norton, at a point 460 feet above the sea. Its western affluents drain this coalfield, its southern tributaries the *Blythe* and *Cole*, drain the tract of Keuper Marls lying between the Dudley and North Warwickshire Coalfields, while the eastern slope of the latter is drained

by another tributary, the *Anker*, which falls into the *Tame* at Tamworth, which there receives the larger portion of the drainage of two coalfields.

The *South Staffordshire Waterworks* "supply area" runs in a south-west and north-east direction from Stourbridge to the *TRENT* at Repton, with an extreme length of about 40 miles, and an extreme breadth at Lichfield of 12 miles. Their main conduit runs along the South Staffordshire Railway from Dudley, by Wednesbury, Walsall, Hammerwich, Lichfield, Fradley, Alrewas, and Branstone to Burton-on-Trent, its limit of supply going east to Wellington, Repton, Hartshorn, and Church Gresley. The eastern limit of supply runs between Smethwick and Birmingham by Sutton Coldfield to the *Tame* at Fazeley, just above Tamworth, crossing that river to the Birmingham and Derby Railway. The railway is the boundary up to the junction of the *Tame* and *TRENT*, at Croxall, thence it follows the latter river up to the Leicester and Burton Railway, as far as Church Gresley up to the county boundary of Leicester, then northward to the *TRENT* again at Repton.

A triangular tract of country between Halesowen, Stourbridge, and Wolverhampton, about 36 square miles in area, forming the south-western portion of the supply area, is situated within the basin of the *SEVERN*. The reservoir at Shavers End is in this tract, the pumping station at Coneygre immediately east of it, as are all other works and pumping stations of the Company. There are reservoirs at Coneygre, Wednesbury, Walsall (north of the main), Cannock Chase (north of the main), Seedy Mill near Longdon, north of the limits of supply, and at Minster and Stowe pools for Lichfield, and at Ontwoods, west of Burton-on-Trent. (From plan of Messrs. McClean and Stileman, C.E.)

The *South Staffordshire Waterworks*' water is derived from a tunnel in the New Red Sandstone, with a borehole in the tunnel. The water stood at the same level from 1857 to 1867, and supplies a very large volume, sufficient for the requirements of 1,000,000 persons. In 1869 the yield was 10,000,000 gallons, which was increased to 24 by driving a

fresh tunnel, 4 miles in length, from a shaft in the Permian Sandstone. It was constructed as far as possible in the rock that gave the best water. The Keuper Sandstone gave the best, and the Upper Mottled Sandstone and Pebble Beds the next, that from the Keuper Marls being the worst. Each mile of the tunnel was found to yield 1,000,000 gallons. It was driven 30 to 50 feet below the surface, 4 feet 6 inches by 3 feet 6 inches in section. Wells at Lichfield have had to be deepened to the level of the water in the tunnel; every well in the town was dried during its construction.

Local Authorities supplied under South Staffordshire Waterworks Act, 1853 (16 & 17 Vict. c. 133), and Acts amending the same. Oldbury, *acres*, 1750; population, 18,821; rateable value, 54,000*l.* Wednesbury, *acres*, 2130; population, 24,564; supply constant; rateable value, 75,304*l.* 10*s.* West Bromwich, *acres*, 5719; population, 56,299; supply partly from private wells; rateable value, 147,219*l.* 15*s.* Coseley, population, 21,701; supply partly from *Wolverhampton Waterworks* and also public wells, as well as the *South Staffordshire Waterworks* supply; rateable value, 53,840*l.* Walsall, *acres*, 8094; population, 58,808; constant supply; rateable value, 141,453*l.* 7*s.* 6*d.*; new works are in progress to supply the higher part of the district.

Mr. Howell* represents Barr Beacon as 780 feet above the sea, of which 350 feet are Pebble Beds, the rest Permian Red and Brown Sandstones with beds of Red Marl, and thin irregular bands of calcareous brecciated conglomerates. Passing from Staffordshire towards the east, a fault east of Sutton Park throws in higher Triassic Beds, the sequence there being Keuper Marls, 410 feet; Waterstones, 180 feet; Mottled Sandstone, 180 feet; at Kingsbury Church, near the River *Tame*, 370 feet of Red Marls overlie the Waterstones, the surface being 410 feet above the sea; a fault brings up a Permian and Coal Measure tract at Huxley and Baxterley, as far as Merevale Church, where a fault brings in the Keuper Waterstones, here increased to 240 feet in

* In Sheet 49 (No. 1) of the Horizontal Sections of the Geological Survey.

thickness, and probably resting directly on the Permian, the Upper Mottled Sandstone being absent.

Bulkington (Warwickshire).—*Acres*, 4793; population, 1590; no public supply; rateable value, 11,862*l.*

Chilvers Coton.—*Acres*, 4136; population, 3005; no public supply; rateable value, 8816*l.*

Birmingham.—*Acres*, 8400; population, 400,757; 343 feet above the sea; constant supply of 8,500,000 gallons, partly from artesian wells and partly from river water. The works belong to the Corporation, purchased from Waterworks Company under 38 & 39 Vict. c. 188, 1875. The rateable value is 1,411,090*l.* 17*s.* Rainfall in 1879, at the Botanic Gardens, 31·98.

The *Corporation* supply.—Manor of Aston, *acres*, 943; population, 53,844; rateable value, 125,760*l.* 1*s.* 4*d.* Saltley, *acres*, 1039; population, 6419; partly supplied from private wells; rateable value, 42,884*l.* 16*s.* 6*d.* Handsworth, *acres*, 3637; population, 22,903; rateable value, 89,646*l.*

At Birmingham, a population of 483,923 inhabitants, living within an area of 15 square miles, receives 8,500,000 gallons daily, three-fourths of the volume of its water supply, from wells in the New Red Sandstone* of a depth of 130 feet to 400 feet, affording water described by the Rivers Pollution Commissioners as "of a uniformly excellent quality," and the Perry Well "being one of the best waters for dietetic and domestic purposes they ever encountered." The yield is as follows:—

	Daily Yield. Galls.
Aston Well (120 ft. deep, bore 400 ft.)	3,500,000
Perry Well (170 ft. deep, 12 ft. diameter)	2,000,000
Short Heath Well (130 ft., 20 in. bore to 400 ft.) ..	2,500,000
King's Vale Well	500,000
Total	8,500,000

* The water drawn for the Rivers Pollution Commission, from the well of the Mint of Messrs. Ralph Heaton and Sons, contained only 0·052 of organic carbon, proving the good quality of the sandstone water extending under the town itself. The hardness being 15·8, all of which was permanent, the well being 300 feet in depth.

The water of the Aston Well rises 8 feet above the surface of the ground; that of the Perry Well only possesses 9·7 degrees of hardness.

The remainder of the supply is impounded from various streams constituting the head water of the *Tame*, an affluent of the *TRENT*, flowing into open subsidence reservoirs of an aggregate area of 89 acres and a capacity of 200,000,000 gallons, whilst another to hold 300,000,000 is in course of construction at Whitacre. The drainage area of the *Bourne* above the Company's intake is 15 square miles, sparsely populated; that of the *Blythe*, 79 square miles, with about the same actual delivery; but the water far worse in quality, containing a dangerous amount of organic impurity. *Plants* Brook, which receives the *Sutton* Brook, into which the Borough of Sutton is drained, is also pumped, as is *Wilton* Brook, draining agricultural land, and yielding 500,000 gallons daily, and *Perry* Brook, near Birmingham, which furnishes somewhat better water. The Company have power under this act to pump the *Tame* itself, and without previous filtration, to distribute it for domestic consumption.

Tamworth has 4888 inhabitants, with a rateable value of 8403*l.* 2*s.* It has no public water supply, and before this can be effected other townships must be included within the Urban District. Houses are now supplied only by their own wells and pumps.

Mr. Henry J. Martin, M. Inst. C.E., in a report to the Tamworth Rural Sanitary Authority on its water supply, gives the analysis, by Mr. W. Jones, F.C.S., of 22 samples of water from streams and springs in this district. Six test wells, sunk with Abyssinian tube, 10 to 30 feet in depth, in the drift of the *Tame* and *Anker* valleys, gave waters of from 11°·39 to 34°·31 (Clark) of hardness. Four springs in the Keuper Marls gave waters ranging from 15°·47 to 29°·66 of hardness. A boring at Bole Hall in the Keuper Waterstones was 26°·33. Springs from the Pebble Beds at Hopwas ranged from 9°·39 to 28°·56. The river *Tame* gave 19°·68.

Lichfield.—*Acres*, 3232; population, 8360. An ancient

well 84 feet above the city, another 45 feet deep in the valley, pumped by steam, give a constant supply of 85,000 to 195,000 gallons a day. Both wells flow into a reservoir. Works carried out under an ancient Trust called the Lichfield Conduit Lands. Rateable value, 28,107*l.* The total solid impurity in the water supplied to the town is 34·24, hardness 21·8, of which 9·7 was permanent; chlorine was 2·80, and the water slightly turbid.

The watershed traversing the Keuper Marls, separating the head waters of the *Blythe* from the *Avon* basin, is 464 feet above the sea, where crossed by the canal connecting Birmingham and Stratford, and 346 where crossed by the Warwick Canal. The *Blythe* is 13 miles in length; it drains the country round Abbots Bromley, Kingston, Bramshall, and Solihull. Shortly before falling into the *Tame* at Coleshill, it receives on its left bank the *Cole*, which also drains a Red Marl district.

The structure of the country lying between the *Avon* and the *Tame* is seen in Sheet 83 of the Horizontal Sections of the Geological Survey, by Mr. Howell. West of Coventry the Permian consists of Red, Brown, and Purple Sandstone, and Conglomerates with Red Marls interstratified, reaching a thickness of 670 feet, and overlying the Coal Measures, which are brought to the surface by a southerly downcast fault, $1\frac{1}{4}$ mile north of Fillougley Church; the *Spirorbis Carbonarius* Limestone there being 500 feet below the surface, and 100 below the sea-level. The Permians are again thrown in by a fault with a northerly downthrow, and crop to the surface at Baddesley Ensor; Coal Measures capped by Permian at Hermitage Hill continue to a fault throwing in the Waterstones 150 feet thick in the valley of the *Anker*, near the Coventry Canal and Trent Valley Railway west of Rye Hill.

River Anker (tributary of *Tame*).

This river has a length of 21 miles; its southern margin is the *Avon* watershed, which is crossed by the Coventry Canal at 316 feet above the sea; its western margin is the *Blythe* watershed, traversing the northern part of the

Warwickshire Coalfield; east it is bounded by the watershed of the *Soar*. The country lying on its right bank consists entirely of Keuper Marls.

Market Bosworth (sub-district).—*Acres*, 34,700; population, 6409.

Atherstone.—Population (sub-district), 14,390. Former supply from shallow wells; proposed supply from higher spring, which has a total solid impurity of 16·10, a hardness of 10·1, all of which was permanent. Chlorine was 1·70 part per 100,000.

Polesworth.—(No information.)

Nuneaton.—*Acres*, 6021; population, 8465; no public supply, wells; rateable value, 26,210*l*.

River Mease (tributary of *Tame*).

This river has a length of 15 miles; rises in the Ashby-de-la-Zouch Coalfield, and flows south until it reaches the Keuper Waterstones, and then turns west, flowing first over them and then over the Keuper Marls, falls into the *Tame* near its junction with the *TRENT*. The most eastern traces of the Pebble Beds of the Bunter occur in this basin; in the *Soar* Basin they have thinned out.

Ashby-de-la-Zouch. — Population, 4536; intermittent supply given, *Local Board Waterworks;* supply pumped into a water-tower from two brooks; the water is filtered; rateable value, 16,500*l*.; 11 & 12 Vict. c. 63.

Ashby Woulds.—Population, 2929; public supply preparing; rateable value, 7916*l*. 15*s*. 11*d*.

Whitwick.—*Acres*, 3383; population, 3882; supply from springs; rateable value, 10,926*l*. The Rivers Pollution Commission analyzed six shallow wells, which showed a high degree of total solid impurity and previous sewage contamination, and a hardness of 13 to 24.

The south bank of the *TRENT*, from the infall of the *Tame* to that of the *Soar*, consists of Waterstones and Pebble Beds faulted against the Ashby Coalfield as far as Melbourne, and then of Waterstones underlying Keuper Marls forming the upland plain.

River Soar (tributary of the *TRENT*).

This tributary drains a large area consisting of impermeable Lias Clays, Keuper Marls, and Charnwood Forest rocks. It is 34 miles in length, rising near the *Avon* watershed, south of Hinckley.

In Horizontal Section, Sheet 46 (No. 1), of the Geological Survey, Professor Hull represents the trigonometrical station of Bardon Hill, Leicestershire, as 890 feet high, consisting of a mass of Greenstone, overlaid to the south-east by Cambrian Grits and Quartzose Slate, and to the north-west by Red Marls and Keuper Waterstones resting on Coal Measures; the Marls are 250 feet thick and the Waterstones 150. The south-easterly dip causes the Trias to thin out at Whitwick, and the underlying Coal Measures to crop to the surface; they are underlaid by 350 feet of Millstone Grit, coarse Red Grit with pebbles of quartz, felspar, and slate, 40 feet of Upper Limestone shale, and the Carboniferous Limestone near the fault, which brings in the Triassic Pebble Beds 3 miles south-east of the *TRENT* near Repton, over which, at Arkeith Hill, occurs an outlier of Keuper Waterstones, 100 feet, and Red Marls, 30 feet, the Pebble Beds being 250, and resting on the Coal Measures.

In *Leicestershire* Mr. James Plant, F.G.S., reports to the British Association Underground Water Committee:—

1. That the Lower Lias Beds of the Midland districts do not give any constant supply of water. The small quantity found at some places is very hard, and is generally contaminated with sulphuretted hydrogen, arising from the decomposition of the iron pyrites that occurs so frequently in these Lower Lias shales.

2. The Rhætic Beds and Upper Keuper Marls (where the Upper Gypsum Bed has been penetrated) yield a good supply of *hard* water, containing, besides carbonate of lime, sulphate of lime to the extent of 100 grains to the imperial gallon. The water is very transparent and very palatable, and is admirably adapted for brewing the fine kinds of beer, when

diluted so as to reduce the proportion of sulphate of lime to about 40 to 50 grains per gallon.

3. When the Upper Keuper Sandstone is penetrated *below the Gypsum* Beds, from which it is separated by a considerable thickness of Marl (chocolate colour) *impervious to water*, a great supply of water is found, in some places free of lime altogether, both of carbonate and sulphate, but in others it is still too hard for the profitable generation of steam. The water in this sandstone depends upon the "outcrops" at various places of the bed, where they have a dip of about 5° to 8° south-east.

For many years water, good in quality and abundant in quantity, has been known to exist at the base of the Great Gypsum Bed which lies in the Upper Keuper Marls. This supply has been proved wherever the Marls have been penetrated in wells from 30 to 80 feet in depth, and in excavations for brick-making, &c.

In one of these excavations near the town of Leicester, on the base of the Gypsum being reached at a depth of 40 feet, and the last layer cut through, a copious supply of clear water burst through in such abundance as to require special arrangement to carry it to an adjacent brook. The water was found to have worn a deep channel in the Red Marl lying immediately beneath the Gypsum. The stream remains constant in dry and wet weather.

The Marls above and below this Gypsum Bed are quite dry and free from water, and the water occurring in it must be derived from the various outcrops of this bed in Nottinghamshire, Derbyshire, and Leicestershire.

Mr. Plant has been led to conclude that this water, running constantly at the base of the Gypsum Bed, must be the source of supply of sulphate of lime found in the underground waters of the Midland Counties; and he has always found it difficult to account for the water found in the deep wells (pump and draw wells) in the Upper Red Marls of this county whenever the Gypsum Bed was penetrated; he is now of opinion that, as far as domestic and farming require-

ments are concerned, in the Upper Red Marl district this horizon affords the most abundant and valuable source of supply.

4. When the thick beds of Red and Gray Marls lying between the Upper and Middle Keuper Sandstone (Waterstones) are bored through, they are generally found quite *dry*, and free from water; but as soon as the Middle Keuper Sandstone is penetrated to any depth *water is always found in great abundance and purity*. The extraordinary supply in this Sandstone is well shown in the Ellistown Shaft, the beds there delivering (at 300 feet deep) 60,000 gallons per hour for weeks together, while the shaft was being sunk, and before the tubing could be put in.

In another instance, these Waterstones yielded a column of pure limpid water from a depth of 670 feet, the column rising 20 feet above the surface; a total of 690 feet.

Leicester.—*Acres*, 2919; population, 122,351; constant supply of 2,500,000 to 3,000,000 gallons from storage reservoir, collecting surface drainage from two Catchment Basins at Thornton and at Bradgate; two service reservoirs, one at New Park and another at Gibroes; the water is filtered; rateable value, 313,606*l*. The Corporation in 1878 acquired the works, executed under Leicester Waterworks Act, 1847; Amended Act, 1851; Extension Act, 1866; Additional Capital, 1875. The works also supply Belgrave, *Acres*, 13,081; population, 2049; about 8000 gallons a day; rateable value, 21,187*l*. 17*s*. In 1871 the Rivers Pollution Commission found the total solid impurity of the water-supply to be 26·32, and the total hardness to be 24·8, of which 9 was permanent. Rainfall in 1879 at the Town Museum, 27·65.

Quorndon.—*Acres*, 2131; population, 1816; no public supply, shallow private wells in gravel and sand; rateable value, 8265*l*.

Thurmaston.—*Acres*, 1640; population, 1748; no public supply; shallow wells; rateable value, 8926*l*.

Loughborough.—*Acres*, 5820; population, 14,733; supply

from the *Wood Brook;* rateable value, 44,103*l.*; under Loughborough Local Board Act. Rainfall in 1879, 27·70.

Hinckley.—*Acres*, 3435; population, 7673; private wells; rateable value, 17,618*l.*

In Lancashire and Cheshire, below the soft, fine-grained sandstones and shales, or Keuper Waterstones, occur massive building stones, with soft beds traversed by current-bedding on the top, between which and the overlying, evenly-bedded Waterstones there is a well-marked junction. The line of boundary going eastwards is seen to gradually overlap the older rocks, the Lower Keuper building stones being reduced to a few feet at Nottingham, and being entirely absent in Warwickshire and the greater part of Leicestershire. These remarks will explain the true Waterstones resting in some of the following sections on the Palæozoic rocks. The sections were collected by Mr. James Plant, F.G.S., of Leicester, for the British Association Underground Water Committee.

Hawkesbury Pumping Station, Coventry Canal (Mr. Sinclair), 252 feet above Ordnance Datum:—

Drift	30 feet.	
Waterstones	90 „	(White sandstone.)
	120 „	

Holywell Boring, Hinckley Local Board (+330 O.D.):—

Drift (clay and gravel) ..	150 feet.	
Red Marl	20 „	
Waterstones	370 „	(Shale, gypsum, and sandstone.)
	540 „	

Elmsthorpe, Leicestershire (+300 O.D.):—

Drift	10 feet.
Red Marl	120 „
Waterstones	330 „
Coal Measures	980 „
	1440 „

Linridge Hall Colliery Boring, Desford (400 feet above Ordnance Datum):—

Drift	2 feet.
Upper Keuper Sandstone ..	20 „
Red Marl and Gypsum ..	44 „
Waterstones	204 „
	270 „

Near Desford, close to 9 milestone on Leicester Railway :—

Marl	213 feet.
Waterstones	140 „
	350 „ to Slate.

Austy Paper Mill, near Leicester (+225 O.D.):—

Drift (boulder, clay)	70 feet.
Red Marl and Gypsum ..	117 „
	187 „

Hathern, Leicestershire—north of Charnwood Forest (+ 320 O.D.):—

Drift	10 feet.
Red Marl	110 „
Waterstones	140 „
*Conglomerate (Lower K.S.)	60 „
	320 „

Chilwell Boring, Leicestershire (+ 450 O.D.):—

	Ft.	In.
Drift	13	8
Upper Keuper Sandstone	53	0
Red Marl	53	4
Waterstones	115	0
Soft Sandstone (Upper Bunter?) ..	110	4
Conglomerate	30	8
Lower Mottled Sandstone	44	4
Permian	15	5
	435	9 Carried to 1036 ft.

* These Conglomerates are well seen at Castle Donington, eastward of which they thin out, and the Waterstones, Middle Keuper, rest directly on the older rocks.

River Wreak (tributary of the *Soar*).

This river has a length of 21 miles, rises on the opposite side of the diagonal watershed to the source of the *WITHAM*, at the base of the Oolites, flows over the Lias through the Vale of Catmos, and falls into the *Soar*, half-way between Loughborough and Leicester, at an elevation of about 160 feet above the sea. The river is navigable up to Melton Mowbray, 236 feet above the sea, from which it is canalized to its source, 362 feet above the sea, near Oakham.

Melton Mowbray.—*Acres*, 2524; population, 5766; no public supply; rateable value, 16,693*l*. Rainfall in 1879, 29·37.

In this basin is Syston, 163 feet above the sea, with a rainfall in 1879 of 24·99, in 1880 of 32·91 inches, Frisby, and Saxby. The registration sub-district of Syston contains 10,860 acres, with a population of 6023.

Returning to the south bank of the Trent, and proceeding eastwards, it receives the waters of *Fairham Brook*, draining impermeable Keuper Marls and Liassic Clays.

These formations extend to the Vale of Belvoir, which is traversed by a canal connecting the *TRENT* at Nottingham and Grantham on the *WITHAM*. The canal commences at Nottingham at 73 feet, and rises steadily eastwards, passing the head-waters of the *Devon* at 163 feet, and crossing the *WITHAM* watershed at 213 feet.

SOUTH-EASTERN HUMBER STREAMS.

River Devon.

This river is 19 miles in length; it rises on the Lias north of Melton Mowbray, and flows over it and impermeable Keuper Marls, its course being nearly parallel to the *TRENT* and the *WITHAM* watershed; it falls into the former stream at about 40 feet. Cotham and Belvoir Castle are in the ground drained by this stream, which receives the River *Smite* on its west bank.

The *TRENT*, from Newark to Gainsborough, flows but a

very short distance from its watershed, the ground entirely consisting of impermeable Keuper Marls and Lias.

NEWARK.—*Acres*, 1889; population, 14,019; supply partly from private wells and partly from wells of Waterworks Company, who pump it into a reservoir; rateable value, 41,973*l.*

GAINSBOROUGH (Lincoln). — *Acres*, 3156; population, 10,964; supply 200,000 gallons, pumped from *TRENT* and filtered; rateable value, 29,058*l.*; Gainsborough Water Act, 1865. Increased filtering beds required, and duplicate machinery. Rainfall at Manchester, Sheffield, and Lincolnshire Railway Company's station, 76 feet above the sea, in 1879, 20·64; in 1880, 27·24 inches.

The *TRENT* is navigable up to Gainsborough. East of this town the watershed retreats further from the river, and the tract is drained by a tributary, the River *Eau*, with a length of 8 miles. In its basin are Messingham, Kirton, Hemswell, Harpswell.

RIVER ANCHOLME (*L*).

This river has a length of 25 miles; area, with its tributary the River *Race* (11 miles in length), 244 square miles, of which the Lias occupies 14 square miles, Oolites 171, Greensand and Gault 36, and Chalk 23. The western watershed, separating this basin from the *TRENT*, follows the strike of the base of the Oolites. The northern watershed, separating it from the basin of the *WITHAM*, ranging east-north-east by Market Rasen, crosses the oolites from their base to the overlying Cretaceous rocks, crossing the Neocomian and Gault escarpment, and passing on to the Chalk. The eastern watershed, separating this basin from the streams falling into the mouth of the *HUMBER*, between Barton-upon-Humber and Donna Nook, follows the strike of the base of the Chalk. With the exception of the Gault, and a portion of the Oolite, the whole of this basin consists of permeable formations.

BRIGG (Lincoln).—*Acres*, 316; population, 3107. Brigg

and Wrawby supplied under private Act of Parliament by waterworks belonging to V. D. H. Cary Elwes, Esq. Broughton is supplied by a conduit from waterworks belonging to the Earl of Yarborough at Castlethorpe. Rateable value, 7582*l.* 18*s.* 9*d.* Rainfall at Brigg Station, 16 feet above the sea, in 1879, 24·60; in 1880, 28·61 inches.

Broughton.—*Acres*, 6854; population, 1299; supply constant from springs and wells; rateable value, 8883*l.* 5*s.*

Roxby-cum-Risby.—*Acres*, 4723; population, 417; pure water is said to be given by private wells at each house; rateable value, 6604*l.*

Winterton.—*Acres*, 3488; population, 1601; private wells; rateable value, 7803*l.* The town has been subject to epidemic typhoid fever for several years. In 1867, Dr. Thorne, now of the Local Government Board, was sent down to inquire into the causes by the Medical Department of the Privy Council, and found the drainage good, but the wells badly polluted.

In this basin are Saxby, Glamford Briggs, Wadingham, Middle Rasen, Dore, Market Rasen.

O.S. CATCHMENT BASIN LI.

Area, 122 square miles, about 2 of which consist of Neocomian and Gault, and the remainder of Chalk, the eastern half of which is entirely concealed by a thick covering of Glacial Drift.

Barton-upon-Humber.—*Acres*, 8140; population in 1881, 5339; supply constant from wells and boreholes in Chalk; rateable value, 20,733*l.*

Castor and Great Limber are in this basin.

O.S. CATCHMENT BASIN LII.

Area, 39 square miles, of which 3 are Neocomian and Gault, and the remainder Chalk, largely covered with thick Glacial Drift.

Great Grimsby.—*Acres*, 1838; population, 29,682; supply

constant of 450,000 gallons, from reservoir storing water pumped from borings in the lordship of Little Coates, about a mile from the town; rateable value, 70,848*l.* 15*s.* Works carried out under 26 & 27 Vict., 1863, by *Great Grimsby Waterworks Co.* (*Limited*). The Rivers Pollution Commission states, that the well in the Chalk 300 feet deep, at the Docks, had a total solid impurity of 32·40, and hardness of 22·1, of which 7·6 was permanent; chlorine 5·00; the water was clear and palatable. The springs supplying the town had a total solid impurity of 27·26, and hardness of 20·6, of which 6·3 was permanent; chlorine, 1·80; rainfall at the Manchester, Sheffield, and Lincoln Railway Co.'s Station, 42 feet above the sea, in 1880, was 28·45 inches.

Clee with Weelsby.—*Acres*, 2246; population, 10,459; constant supply from Grimsby Co.; rateable value, 13,951*l.* 15*s.*

Cleethorpes with Thrunscoe.—*Acres*, 1029; population, 2844; supply from springs and pumps; rateable value, 7305*l.*

Irby and Waltham are in this basin.

RIVER LUDD (LIII.).

The length of this river is 7 miles; area 139 square miles, of which Neocomian and Gault occupy 3, and Chalk the remainder; nearly half of the latter being concealed by thick deposits of Glacial Drift, which covers the entire coast of Holderness.

Louth.—Population, 10,690; supply from works of Louth Waterworks Co. (Limited), and from private wells. Rainfall in 1879, at 111 feet above Ordnance Datum, 28·92; at 380 feet above the same it was 30·86. In 1880 the figures were 35·04 and 38·45 inches respectively.

North Cotes and Conisholme are in this basin.

WITHERN EAU, &c. (LIV.).

The length of this stream is 13 miles, and it drains 189 square miles, of which Neocomian and Gault occupy 9,

and chalk 180, more than half the latter being covered with the Holderness Glacial Drift.

In this basin are Burgh-Withern and Saltfleet. This is the last of the basins draining into the mouth of the *HUMBER*.

Population in the Southern Group of the Humber Basin.

In Census 1871.

River Trent, &c.	Counties.	Population.	Density. Acres to Persons.	Proportion of Population probably living in this Group.	Population, about.
	Lincoln	463,163	4·0	$\frac{2}{3}$	185,264
	Nottingham ..	319,956	1·6	All	319,956
	Leicester	268,764	1·9	$\frac{1}{50}$	5,300
	Rutland	22,070	4·0	$\frac{1}{3}$	7,356
	Warwickshire ..	633,902	0·8	$\frac{2}{3}$	400,000
	Staffordshire ..	857,333	0·8	$\frac{9}{10}$	771,600
	Derbyshire	380,538	1·7	$\frac{3}{5}$	228,324
	In Census 1881.				
	Lincoln	469,994	3·7	$\frac{2}{3}$	187,996
	Nottingham ..	391,984	1·3	All	391,984
	Leicester	321,018	1·5	$\frac{1}{50}$	6,413
	Rutland	21,434	4·4	$\frac{1}{3}$	7,144
	Warwickshire ..	737,188	0·7	$\frac{2}{3}$	491,459
	Staffordshire ..	981,385	0·7	$\frac{9}{10}$	883,247
	Derbyshire	461,141	1·4	$\frac{3}{5}$	276,684

CHAPTER VII.

RIVER-BASINS LYING EAST OF THE DIAGONAL WATERSHED.

The Fen Streams.

It will be noted that an important watershed crosses England diagonally from north-east to south-west, separating the basins of the *SEVERN, TRENT,* &c. on the one side, from those of the *THAMES,* east coast streams, *WITHAM* and *OUSE* on the other. This line nearly separates all the strata up to the top of the Trias, from the Lias upwards. Commencing on the Chalk strata of the Isle of Purbeck, it ranges from Crewkerne, at the top of the Oolites across England, by Cheltenham and Chipping Campden, gradually resting on somewhat lower rocks. In advancing to the north-east, it passes over the Lias near Rugby, and reaches the Keuper Marls at Gainsborough, where 6 square miles or so pass over the boundary, forming the only exposure east of that line. At Scarle, near Lincoln, and Burford, in Oxfordshire, the Trias has been reached and penetrated beneath the overlying Oolites, but south of the latter locality it probably thins out against the old Palæozoic ridge underlying the *THAMES* valley, connected with the Mendip range, which latter, though capped more or less by New Red Marls, was doubtless above water when the New Red Sandstone was deposited, and east of a line ranging through Gloucester and Stamford; the chance is very small of the New Red or Permian being present in sufficient thickness to be water-bearing.

As already stated, the diagonal watershed, passing across England from south-west to north-east, is situated mainly on the Oolitic strata. West of it, they only occur in three areas, viz., 768 miles in the *SEVERN* and tributary basin, all of which drain underground into the *THAMES* Basin; 171

square miles in the *ANCHOLME* valley, draining naturally into the *HUMBER;* and 852 square miles in the Cleveland district of Yorkshire, of which 183 miles are north of the *TRENT* Basin, though the underground drainage flows towards and under it.

The diagonal watershed nearly corresponds with the north-west boundary lines of the counties of Lincoln, Rutland, Northampton, Oxford, Bucks, Wilts, and Dorset, the water falling on the Oolites in the basin of the *WITHAM* and *OUSE* of the first three of these counties, and Huntingdon and Bedford drains underground beneath the cretaceous rocks of Norfolk, Suffolk, and Herts, in the basin of the *THAMES* and east coast. The watershed between the *THAMES* and *OUSE* commences at a point on the diagonal watershed near Weedon, at the base of the Oolites; then it cuts across the strike of these rocks, passing over higher and higher beds until it ascends the Chalk escarpment near Tring, where it travels north-eastward, and nearly follows the strike of the Chalk, rising to an elevation of 500 feet near Baldock, and, with somewhat diminished height, forms the central watershed of Norfolk and Suffolk.

The Tertiary deposits are chiefly impermeable; they occur entirely east of the diagonal watershed, and occupy 3333 square miles in the *THAMES* and east coast basins; they are everywhere *suprapervious*, resting on the cretaceous rocks, now being bored into at several points by the *New River Company* and other Companies, and long drawn on by the London brewers.

Of the 10,506 square miles of cretaceous rocks in England, only 1329 miles occur west of the diagonal watershed, 999 in Yorkshire in the *TRENT* and *HUMBER* Basin; 16 miles west of the line, but draining underground into the *THAMES*, and 257 miles in South Devon, forming the Blackdown beds. In the *THAMES* and east coast district are not less than 4000 square miles of pervious cretaceous rocks, receiving not less than 5 inches of rain annually, or a daily absorption of 800,000,000 gallons. It is readily understood with these

figures how the dry weather flow of the *THAMES* is kept up, by Chalk springs; one-fifth of this yield is sufficient for 4,000,000 people; and taking the Oolite supply, the total volume of water absorbed by underground sources in the *THAMES* and east coast river-basins may be taken at 1,125,000,000 gallons, a supply equal to the wants of 22,000,000 people, or nearly that of the total inhabitants of England, supposing the whole of the 5 inches of rainfall absorbed could be pumped up.

The Cretaceous rocks occupy 2038 square miles in the *WITHAM* and *OUSE* Basins, about 1500 square miles being pervious. Those of the *HUMBER* Basin have already been described.

The streams reaching the seacoast between Dogger Head and Cromer form a natural east coast group, draining into the WASH:—

RIVER STEEPING (*LV.*).

This river is 18 miles long, draining 101 square miles, in which are situated Wainfleet, Spilsby, and Greetham. Of the geological formations 75 square miles are covered with Alluvium, 20 square miles consist of Greensands and Gault, and 6 of Chalk.

RIVER WITHAM (*LXXIII.*).

This stream drains 1079 square miles; it has a length of 40 miles. Chief places, Boston, Tattershall, Lincoln, 16 feet above the sea; Claypole, 69 feet; Grantham, 170 feet. Its tributaries are the *Till*, 14 miles long, with Saxelby, Willingham, and Upton; the *Bain*, 24 miles long, with Coningsby, Horncastle, and Farforth; the *Brant*, 13 miles long, with Broughton-on-Brant and Brandon; the *Langworth*, 9 miles long, with Barlings and Wragby. These streams drain 6 square miles of Trias, 240 of Lias, and 797 of Oolites, all of which latter are covered with alluvial deposits, and 36 of Greensands and Gault. Deep borings made in different parts of the country, in search of coal, have afforded many facts of interest in showing the exten-

sive denudation of the Carboniferous surface and still older rocks that took place before its deposition, and also the occurrence of springs of good water lying in the Trias beneath the Lias and Oolites. One of these at Scarle, near Lincoln, passed through the following series (classified by Professor Hull):—

	Feet.
Alluvial, or Drift strata	10
Lower Lias (gypsum)	65
Rhætic beds	66
New Red Marl	573
Lower Keuper Sandstone	244
New Red Sandstone (Bunter)	542
Upper Permian beds	384
Lower Permian sands	16
Carboniferous (1900—2030)	130

The boring is situated on the *TRENT* and *WITHAM* watershed near Swinderby, between Lincoln and Newark; the level is about 35 feet above the sea. Water occurred at a depth of 950 feet, and rose 6 feet above the surface; it must have been derived from the outcrop of the Keuper Sandstone 12 miles distant, on the left bank of the *TRENT*, south of Worksop, at an elevation of about 100 feet, giving a loss of head through friction of 59 feet, or about 5 feet per mile.

Mr. Wheeler, C.E., states that the wells sunk in the high land, known as "The Cliff," extending from Grantham to Lincoln, averaging 100 to 150 feet in depth, are affected by the River *TRENT*, 12 miles distant, rising a few hours after a flood in that river.

The labours of Professor Judd, in Lincolnshire, enable the following classification of the bed at the base of the Oolites to be adopted:—

	Equivalents.
Cornbrash	Cornbrash.
Gr. Oolite clays and limestones	Gr. Oolite.
Upper Estuarine series	Stonesfield slate.
Lincolnshire oolite with Collyweston slate at its base	Inferior Oolite.
Northampton sands with Lower Estuarine series	(Lower Freestones.)

The Lincolnshire Oolites are absent in the eastern and southern portions of the Midland district, and the upper estuarine series, which form the base of the Great Oolite series, rest directly upon an *eroded* and denuded surface of the Northampton Sands; when the Lincolnshire Oolites are present, however, they too are found to be eroded, proving them, like the Northampton Sand, to be of Inferior Oolite age.

The basement beds of the Northampton Sands rest, in Rutland and South Lincoln, on an eroded surface of Upper Lias clay, and generally consist of oolitic ironstone rock, forming a bold escarpment, "The Cliff," stretching away for 90 miles through Lincolnshire to Yorkshire, at the base of which copious springs arise, at the junction of the Lias; the beautiful Eleanor Cross at Geddington is over one. Springs are thrown out in a similar situation at Pipwell, where there is the remains of an old reservoir.

At Blatherwyche Park Inlier, one well sunk to the Northampton Sandrock yielded a good supply, but another was strongly impregnated with sulphuretted hydrogen.

At Collyweston, a number of wells have been sunk through the thick beds of the Lincolnshire Oolites, into the "red-rock," or ironstone, which itself supplies the large quantities of water used in the working of the "Slate pits." To this horizon are due the springs of Wolthorpe, collected in a reservoir for the supply of Stamford.

Very copious springs are also given off by the base of the ironstone of Easton, used for the supply of that village.

Near Stamford, a futile attempt to find coal was made by the late Marquis of Exeter, and a depth reached of 500 feet, but the Lias was not penetrated, the upper clay being above 140 feet thick. Water occurs on the same horizon, in the Uppingham *outlier*, issuing from a blue calcareous rock, forming the base of the Northampton Sands, at Lyddington; springs also issue at Bisbrook.

The upper portion of the ironstone is much peroxidized and readily pervious to water, and is called "kale" by the

well-sinkers; the compact lower portion (carbonate of iron) is the water-bearing horizon, but the well-diggers consider it safer to penetrate it, and reach the Lias, "blue-bind," to prevent failure during droughts.

Professor Judd* states the capacity for the absorption of rain of the Northampton Sands and overlying Oolite Limestone is "practically unlimited, for not only do many of the streams flowing over the Boulder Clay instantly disappear underground, by means of swallow-holes, when they reach the junction of the clay and limestone or sand, but drains are carried into them, and artificial swallow-holes produced, that never fail to act even in the heaviest rainfalls."

This water is given off in copious springs on the top of the Lias, and, though containing much temporary hardness, they are never chalybeate.

The Northampton Sands average 20 feet to 30 feet in thickness, and seldom reach more than 40; the overlying Lincolnshire Oolite at Stamford is 80 feet, gradually thickening from thence northwards, and thinning out entirely southwards at Harrington and Maidwell, and eastwards, near Wansford tunnel.

The Fens.—The Banks in the Fens are a characteristic feature, and may be divided into three classes :—

1st. The Old Sea-dykes, attributed by some to the Romans, extending along the coast of East Holland in Lincolnshire, and on the south of the Wash by Holbeach and Godney Marshes, Long Sutton, Tydd, Wisbech, Walton, and Walpole, and thence towards the *OUSE.*

2nd. The Sea Banks, or "Sea Walls," constructed for the reclamation of land from the Wash, of which good examples occur at Wingfield, between the outfalls of the *NEN* and the *OUSE.*

3rd. River and drain Banks; these are often double, the outer embankment being the highest, and often with *wash lands* between. A road is often carried at the top of the

* 'Geology of Rutland,' in Memoirs of the Geological Survey.

bank, and follows the windings of the river; sometimes the waters of the river have been intercepted, and the river has disappeared, but the tortuous highway remains.

According to Mr. Skertchly,* the Roman Banks extended over 150 miles of seaboard, and required 11,000,000 tons of material for their construction; 64,000 acres of marsh-lands have silted up since their construction, chiefly between the outfalls of the *WITHAM* and *OUSE*. He believes the Romans recognized the importance, in designing their drainage works in the Fens, of distinguishing between the natural rain-fall of the district and the floods brought down from the inland country. They surrounded the upland border with a catch-water, now called Car Dyke, which they used for purposes of navigation also, and protected by forts at seven places. The Romans used rivers as the arterial drains, and led the subsidiary drains into them, which system was reverted to at the beginning of the century by Rennie. Little was done in the way of drainage in the Early English period until Richard de Rulos, *temp.* Henry I., reclaimed Deeping Fen. In the period following, from the time of Henry II. to the time of Elizabeth, considerable efforts were made to embank tracts, and carry out efficient drainage, but the natural drainage gradually became worse through the silting up of the outfalls, and various inundations took place in Kesteven and Holland in the 13th and 14th centuries, and the marsh-land in the 13th, 14th, 15th, and 16th centuries. At the end of Elizabeth's reign a scheme for draining a number of Fens was proposed, which was revived in the time of James I. by Thomas Lovell, who was to receive a third part of the land reclaimed, but the work was not carried out. Dugdale states, in 1638, that the outfall of the *Welland* was deepened, and sluices erected by Sir William and Sir Antony Ayloff, and the Fens were covered with grass, but the works were afterwards neglected through civil commotion.

In 1761 the Witham Commission was established by

* 'The Fenland, Past and Present.' Wisbeach, Leath and Son. 1878.

Act of Parliament to drain the lands near the *WITHAM*, and restore the navigation from Boston to Lincoln. The river was deepened, widened, and banked, and the Grand Sluice made, and opened in 1764.

Wildmore, East and West Fens, still remained in a state of morass, containing in Dugdale's time no less than sixty lakes, with distinct names. These Fens were drained by Mr. Rennie under Acts obtained in 1801, 1803, and 1818, the East Fen waters being taken by a cut to Witham at Hobhole, and the West and Withmore Fen waters discharging into the river by Anton's Gowt and Maud Foster's Sluice. These were amply sufficient in the great floods of 1814, but were ineffective in those of 1866, the level of the peat forming the surface of the land having shrunk from being 11 feet above the sill of the Hobhole Sluice to 9 feet above it, while the fall is still further reduced by silting up, to the extent of no less than 5 feet. Since then the water has been lifted by two of Appold's centrifugal pumps, stationed at Lade Bank, with a lift of 6 feet, under an Act obtained in 1867.

According to Stukeley, the *WITHAM* in ancient times flowed from Lincoln to Dogdyke, and thence by East and West Fens to Wainfleet, the *STEEPING* being then a tributary stream, as depicted on Richard of Cirencester's map. The old channel had probably silted up in the 15th century, when merchants established themselves at Boston, and the present channel was not only put in good condition, but the tide flowed in as far as Lincoln, rising 2 feet at Swanpool. In order to prevent tidal overflow, Mayhave Hake, an engineer from Gravelines, was instructed to place a sluice across the river to stop the tidal inflow; the absence of its scour caused an accumulation of sand and silt, which was further aggravated by the banks falling into a bad condition through the dissolution of the twelve monasteries on the river.

The current of the river was still further weakened by the abstraction in 1720 of a large body of water by the North

Forty Foot, draining the land north of Kyme Eau, made by Earl Fitzwilliam. The Fen was not much benefited, and the scour caused by the water was lost between Langrick and Boston. In 1721 vessels drawing 250 tons could come up the river, but it had so silted in 1751 that only vessels of 40 tons could get up, and then only at spring tides. The rain-cloud which produced the great flood commencing at Plymouth about 3 A.M. on the 14th July, 1875, travelled to the north-east at above 20 miles an hour, and reached Boston between 3 and 4 P.M., the quantity of rainfall registered being, according to Mr. W. H. Wheeler, C.E., 1·08 inch in about 36 hours. A long drought had just broken up, 1 inch of rain having fallen on the last four days of June. In July 3·82 inches fell, the average for twenty years being 2·29 inches. The *WITHAM* did not rise until the 17th, and then only a few inches, and its maximum on the 23rd was only 3 feet above the drought-level. The Black Sluice Drain, draining 200 square miles, half of which is Fen, only rose 1 foot. The *Glen*, draining higher ground, was full to the top of the banks, rising to within 8 inches of the flood of April 1872, the highest known.

BOSTON (North Midland Counties, Lincolnshire).—*Acres*, 5073; population, 14,932; spring and surface water near Miningsby, about 14 miles from Boston by gravitation; reservoir; daily supply 320,000 gallons (constant); rateable value, 35,358*l.*; 9 Vict., Sess. 1846, "An Act for better supplying with water the town and environs of Boston, in the county of Lincoln;" hardness, 14·4. During the floods of July, 1875, the reservoir, 30 acres in extent, and draining 3 square miles, rose 10 inches between the 18th and 25th, the brook supplying it running a fair stream, though dry in June. The rainfall for the month was 4·33. The rainfall for the year 1880, at the High Street, 24 feet above the sea, was 35·53 inches.

NEW SLEAFORD.—*Acres*, 5930; population, 4967; rivers, pumps, and wells; rateable value, 18,000*l.*

RUSKINGTON.—*Acres*, 3681; population, 1191; surface

wells in gravel and sand, from which there is an unlimited supply of good water (?); rateable value, 5892*l.*

GRANTHAM.—*Acres*, 406; population, 16,886; springs, reservoir (c.); temperature of springs, 15°·0 C.; total solid impurity, 30·20; total hardness, 23·6, of which 6·5 was permanent; chlorine, 2·05; rateable value, 17,307*l*; the Grantham Waterworks Act, 1873.

LITTLE GONERBY.—*Acres*, 703; population, 2500 (?); supplied by the *Grantham Waterworks Company* (nearly c.); rateable value, 10,390*l.* 3*s.* 11*d.*

SPITTLEGATE, HOUGHTON, and WALTON.—*Acres*, 2052; population, 5304 (?); supplied by *Grantham Waterworks Company* (nearly c.); rateable value, 20,410*l.* 15*s.* 11*d.*

LINCOLN.—*Acres*, 10,689; population, 37,312; gathering-ground of gravel, reservoir, 24 acres (c.). The Rivers Pollution Commission states the total solid impurity to be 18·88; total hardness, 8·0, of which 7·6 was permanent; chlorine, 3·60. Supply, 260,000 gallons to 5079 houses; rateable value, 95,969*l.* 19*s.* 6*d.*; Acts of 1846 and 1871. Rainfall, 24 to 25 inches, in 1879; 29·54 to 30·44 in 1880.

HORNCASTLE.—*Acres*, 1224; population, 4814: from seven public wells, a large number of private wells, and the Rivers *Bain* and *Waring*, not filtered (constant); rateable value, 14,692*l.*

RIVER WELLAND (LXXIV.).

The length of this river is 42 miles; area, with its tributaries, 760 square miles, of which the Lias occupies 180, and the remaining 580 square miles consist of drift-covered Oolites. Rainfall is 20·6. Chief places, Holbeach, Spalding, 12 feet; Market Deeping, Stamford. Tributaries:—River *Wash*, 19 miles long; chief places, Ryhall and Oakham: River *Glen*, 31 miles long: and River *Chater*, 15 miles long; on it is Preston.

The *WELLAND*, previous to the drainage of the Fens in the 17th century, had two outfalls, the principal in Dugdale's time (1660) being that branching from Crowland,

and thence by the present *South Eas* and *South Holland* drains to the *NEN*, and sea at Crosskey's Wash; the other outfall was the present outfall through Spalding. From 1815 to 1835 this channel was so silted up that the neap-tides did not reach Spalding, but the river was then improved by Mr. Jas. Walker, C.E., by straightening and fascine training, banks being made of thorn faggots, 6 feet long and 3 feet girth, weighted with clay, and laid in rows, until the bank was raised to half-tide level. The thorns interlaced, and material was soon deposited in and on the back of the fascines, and they now resist the strongest currents.

STAMFORD (Lincolnshire).—*Acres*, 1766; population, 8775. From springs thrown out by the Lias Clay beneath the ironstones of the Lower Oolites, yielding 100,000 gallons in 24 hours, stored in a reservoir at Wothorpe, holding 300,000 gallons, about a mile and a quarter, and from a pond known as Whitewater Pond, situate about two and a half miles from the town. The supply is deficient in quantity. The Wothorpe supply is good, but as regards Whitewater the quality is bad. The Wothorpe supply is hard, being 34·4, of which 8·1 is permanent; the total solid impurity is 46·48, and chlorine 2·70. The quantity running into Wothorpe reservoir in 1871 was estimated by Mr. Hawksley to be in dry weather 58,000 gallons per day. In February 1874 it was 102,456 gallons per day, and Mr. Bateman then estimated the average daily supply at less than 80,000 gallons. The average daily supply from Whitewater is unknown to the Sanitary Authority, but that supply failed last year, and at the present time, owing to inferior quality, the Whitewater supply is cut off, and, from the want of a proper supply, great and justifiable complaints are made by the inhabitants. Rateable value, 26,939*l.* 3*s.*; 7 Will. IV. and 1 Vict. c. 20, 40 Vict. c. 34. Rainfall in 1879, at 116 feet above the sea, was 23·26; in 1880 it was 33·74.

SPALDING. — *Acres*, 10,384; population, 9260; artesian well at Bourne, thence 10 miles in pipes to Spalding tank, holding 40,000 gallons, and 80 feet above the town (c.);

rateable value, 47,624*l.*; the Spalding Waterworks Act, 1860. The old water supply of Spalding was pumped from the *WELLAND* at Pode Hole, and had a total hardness of 17·7; total solid impurity of 28·48; and chlorine, 2·70. The Bourne well-head has a hardness of 35·2, of which 11·8 is permanent; chlorine, 3·10.

Mr. G. J. Symons * calculates the mean annual rainfall at Pode Hole, 20 feet above Ordnance Datum, as:—

In 1850–9.	In 1860–9.	In 1870–9.
23·38	25·34	24·82

RIVER NEN (LXXXIV.).

The length of this river is 100 miles; area, with tributaries, 1077 square miles. Chief places, Parson's Drove, Peterborough, 28 feet; Oundle, Northampton. Tributaries: *Old Nene*, 42 miles long, with towns of Outwell, Wisbech, March, and Ramsey. The River *Ise* is 22 miles long. Geological formations are 150 square miles of Lias, and 927 of Oolites, covered by alluvium. Rainfall is 21·6 (average).

The *NEN* drainage area above Higham-Ferrers Bridge is 383 square miles, 25 miles from the watershed, and midway between it and Peterborough, on the 20th May, 1849, about 1 inch of steady rain fell, raising the stream from ordinary run of 5000 cubic feet per minute to an average of 32,000 cubic feet per minute, lasting from the evening of the 20th to the 23rd, when the river in a very short time relapsed to its ordinary condition. This flow off, divided by the area, gives 0·156 or $\frac{3}{1\,0}$ of an inch, or $\frac{1}{6}$ of the rainfall. Some flows of this river give three to four times this volume. According to Mr. Beardmore,† at Peterborough the *NEN* drains 620 square miles, and has a total discharge (ordinary summer) of 5000 cubic feet per minute. Discharge per square mile of 8·45 cubic feet per minute, representing 1·88 inch of rainfall per annum, the total average being 23·1

* 'British Rainfall, 1880.' London, Edward Stanford, 1881.

† 'Hydraulic Tables.' By Nathaniel Beardmore, M. Inst. C.E. London, Weale, 1852.

inches per annum. Mr. Shelford, C.E.,* states the greatest flood that has passed through Peterborough Bridge was about 8000 cubic feet per second, equivalent to ½ inch rainfall in 24 hours over the drainage area, or only ¼ the quantity actually received, as determined by Mr. Symons' observations.

Mr. Beardmore† states the fall of the *NEN* is greatly absorbed by mills; its fall is 3 to 12 inches per mile, floods being excessive. Above Peterborough, below weirs, it has a surface velocity of 50 to 70 feet per minute, and a fall per mile of 5 to 12 inches. From Northampton to Wansford it has an average fall per mile of 38·7 inches; between Wansford and Peterborough of 21·8 inches; between Peterborough and Guyhirn, average 2 feet.

Mr. Utting, of Wisbech, Surveyor to the Nen Outfall Commissioners, states that in the *NEN*, between the North Level Sluice and Sutton Bridge, the fall in the ordinary state of the river does not exceed 1½ to 2 inches per mile, and at the height of the flood of March 1848 it did not exceed 4 inches per mile; at the same time the fall from the Horseshoe to the North Level Sluice (4½ miles) was only 6 inches more than ordinary. The fall below Sutton Bridge is ordinarily about 1 inch per mile, though the surface of low water is frequently level. The original dimensions of the upper end of the *NEN* Outfall Cut, carried out by Messrs. Telford and Rennie in 1834, were 410 feet at top, at the level of high water spring tides, 250 feet wide at bottom, and 20 feet deep, giving an area of 6597 square feet. But the section is now much deeper and improved. The sectional area at Wisbech was formerly 1856 square feet, it is now 2500 square feet. In embanking the *NEN* and other Fen rivers, care has been taken to leave a wide margin for floods to expand themselves. These flat basins or reservoirs are locally called "washes." One of these now exists immediately below Peterborough; it is 12 miles long, with an

* 'Min. Proc. Inst. C.E.,' vol. xlv., Session 1875-6, part iii., pp. 81-3.
† 'Hydraulic Tables.'

average width of half a mile, and is used for pasturage in summer. But when it is full, which was the case in 1852, the force of the floods is much increased from the steepening of the gradient.

HARDINGSTONE (Northamptonshire). — Population, 1814. Most of the houses are supplied by the *Northampton Water Company*, but some houses use well water, derived from artesian wells; rateable value, 10,870*l.*

NORTHAMPTON—*Acres*, 1342; population, 51,880; wells, in the Lias, 191 feet deep; total hardness, 10·3, of which 1·7 was permanent; chlorine, 5·15; and other springs; by three large reservoirs; supply 520,000, about 495,000 gallons (c.); rateable value, 137,868*l.*; Northampton Waterworks Company's Act, c. 47, 7th June, 1861.

Mr. Symons* calculates the mean rainfall at Althorp House, 310 feet above Ordnance Datum, as:—

In 1850–9.	In 1860–9.	In 1870–9.
20·34	23·35	26·93

DAVENTRY.—Population, 3859; from land springs; partly from reservoir of Waterworks Company; constant supply; rateable value, 6834*l.* 1*s.*; the works were purchased from the Lord of the Manor, and are recognized in the Local Act of 1806.

The Rivers Pollution Commissioners give the following analyses:—

	Total solid impurity.	Chlorine.	Temp.	Perm.	Total.
Northampton, Garner's Spring	31·36	1·76	17·4	5·9	23·3
Daventry, source of the *Cherwell*	27·30	1·70	16·7	5·7	22·4
Warkton, near Kettering, Cornwells' Spring	40·20	1·95	24·3	6·3	30·6
Warkton, near Kettering Boughton Spring	42·90	1·70	30·0	8·0	38·0

* 'British Rainfall, 1880,' *op. cit.*

Wellingborough. — *Acres*, 4490; population, 13,796; supply, a well in Bush Field, 9 feet in diameter and 22 feet deep, in limestone and ironstone rock, yields 25,000 gallons daily from top springs; pumped into two covered reservoirs, containing about 300,000 gallons; about 70,000 gallons used daily, but the quantity is very variable (c.); rateable value, 42,030*l.* 3*s.* 4*d.*; the Public Health Act; increased supply is required. Rainfall in 1879, at Croyland Abbey, was 28·77; and in 1880 was 33·40 inches.

Kettering.—*Acres*, 2840; population, 11,093; a spring in the parish of Weekley, in the county of Northampton, and two wells, 30 feet deep; reservoir, containing 250,000 gallons; supply 70,000 to 75,000 gallons per day (c.); rateable value, 31,196*l.* 16*s.*; the works have been constructed and are maintained by the *Kettering Waterworks Company* (*Limited*) under the authority of an order of the Board of Trade, confirmed by the Gas and Water Orders Confirmation Act, 1872. Rainfall in 1879, 300 feet above the sea, was 27·45 inches; in 1880 it was 32·41.

Oundle.—*Acres*, 2076; population, 2890; natural spring, and well water; six public pumps (c.); rateable value, 11,912*l.*; Oundle Improvement Act, 6 Geo. IV. c. 32; Improvement Commissioners are aided in their public works and water supply by Oundle Trust Estates.

Peterborough.—*Acres*, 1783; population, 21,219; springs from the Oolitic formation, near Braceborough Spa; artesian well, yielding 800,000 gallons a day; covered reservoir, to contain 1,500,000 gallons, constructed in brickwork and concrete, giving a head of about 140 feet above town (c.); 18-inch main to deliver 1,500,000 gallons daily; rateable value, 68,527*l.*; "An Act to confirm certain Provisional Orders of the Local Government Board relating to the districts of Chelmsford and Merthyr Tydvil and the borough of Peterborough (two)" 39 & 40 Vict. c. 199. Rainfall at Westgate, 32 feet, 21·86 inches in 1879; 31·12 in 1880.

Ramsey (Huntingdonshire).—*Acres*, 16,000; population in 1881, 4617; generally from pumps, and it is considered

that, as a matter of convenience to the inhabitants at the east end of the town, a pump should be erected; there is a good site being obtained, and such works are in contemplation (c); rateable value, 11,711*l.* 1*s.* 9*d.*

Holbeach (Lincolnshire).—*Acres*, 21,133; population, 5190; private wells and rain-water; rateable value, 39,183*l.*

Long Sutton.—*Acres*, 3749; population, 2694; private wells and cisterns; two public wells; rateable value, 9227*l.*

Sutton Bridge.—*Acres*, 5362; population, 2160; from sinking wells and catching rain-water; rateable value, 3980*l.* 5*s.*

Chatteris (Cambridgeshire).—*Acres*, 13,394; population, 4712; chiefly wells in gravel; rain-water is used by some; in the Fens, water from the Fen rivers is used (c.); rateable value, 30,005*l.* Rainfall at Horseway Lock, in 1879, was 21·56; in 1880 it was 24·46 inches.

March.—*Acres*, 18,921; population, 6190; private storage of rain-water, and supply from public and private wells; rateable value, 48,859*l.*, including all land within the parish of March.

Whittlesey.—*Acres*, 640; population, 3681; wells; the Rivers Pollution Commissioners' analyses show the water to be very hard and much polluted; those from Abyssinian pumps in a field were the best; rateable value, 5413*l.* 15*s.* 11*d.*

Wisbech.—*Acres*, 6430; population, 9362; the *Wisbech Waterworks Company* supply numerous houses in the town from springs out of the Chalk at Marham, Norfolk, whence they derive their supply. The water flows into a small reservoir, and from thence through 8 miles of pipes to the pumping station. The other parts of the district are supplied from wells and cisterns, and to some small extent from the River *NEN* (by dipping), and from pits (intermittent); rateable value, 36,228*l.*; the Wisbech Waterworks Act, 1864 (27 & 28 Vict. c. 180).

Walsoken.—*Acres*, 4872; population, 2696; the *Wisbech Waterworks Company;* other parts of the district are supplied from wells, cisterns, and pits; there is one public

pump in the district (I.); rateable value, 12,563*l.*; the Wisbech Waterworks Act, 1864 (27 & 28 Vict. c. 180).

RIVER OUSE (LXXXV.).

The length of this river is 143 miles; area, with its tributaries, 2667 square miles, of which 11 are occupied by Liassic strata, 1316 by Oolites, 350 by Greensands and Gault, and 930 by Chalk. Average rainfall, 21 inches.

The *GREAT OUSE* from Huntingdon to Holywell runs east, and then, skirting the edge of the Fen Country, flows north-east to Earith, where it enters the Fens. Formerly it traversed them by several branches, one flowing north falling into the old River *NEN* at Benwick, another, its present course, passing east and then north, skirting the Island of Ely, known as the *West River*, receiving the *Cam* at Thetford, but until it receives this tributary no volume of water is conveyed; its drainage being intercepted by the Old and New Bedford Levels, running for 20 miles to Denver. The old *West River* and *Cam* formerly flowed north-west from Littleport, the streams being called the *Old Croft* and *Old Welney*, crossing the Bedford Levels, at Welney, thence to the *NEN*, at Upwell, and by Wisbech to the sea. The present course of the *OUSE* from Littleport to the infall of the *Brandon* or *Little Ouse* is an artificial cut of very ancient date; from thence it flows through the channel of the *Little Ouse* to the sea at King's Lynn, which now receives, in addition to the drainage of 200 square miles in the *Little Ouse*, 2700 in the *GREAT OUSE* Basin. The top-waters of the Bedford river at Denver being 8 feet above the *OUSE*, necessitated the making of a sluice to prevent the flowing back into the *OUSE*. The old circuitous channel of the *OUSE*, between Eau Brink and Lynn, traversed 5 miles. In 1720 Mr. N. Kinderley designed the Eau Brink Cut across the marshes, shortening the course to 2½ miles in length. This was completed in 1825 by Mr. Rennie, according to the award of Messrs. Huddart and Mylne. The area

of the Cut, just below Free Bridge, at low water spring tides is 2620 square feet, the depth being 11 feet 9 inches, or 26 feet 3 inches at high water springs, with a sectional area of 7879 square feet. The average fall per mile, from Denver Sluice to Free Bridge, during the six-weeks' flood from October 9th to November 19th, 1848, was less than 7 inches per mile, and the maximum under 9 inches per mile. These works lowered low-water mark in Lynn Harbour 4 feet, but they were still 5 feet higher than in the road outside, until Sir John Rennie cut a channel to Lynn Deeps.

Godmanchester (Hunts).—*Acres*, 4667; population, 2188; natural wells and springs (constant); rateable value, 19,072*l.*

Huntingdon.—*Acres*, 975; population, 4229. Springs at the foot of a hill, which are conveyed, by means of pipes, to a well, and from thence pumped to a reservoir; daily supply, 40,000 gallons. The quantity used varies according to the weather. In hot weather more used for watering. Rateable value, 18,186*l.* Public Health Act, 1875.

St. Ives (Hunts).—*Acres*, 2115; population, 3036; pump in bed of gravel 4 feet thick; rateable value, 14,303*l.*

St. Neots.—*Acres*, 1476; population in 1881, 4261; natural springs; rateable value, 19,172*l.*

Bedford.—*Acres*, 2200; population, 19,532; from a well in the Oolites, 30 feet deep, with headings of 150 feet and 75 feet at that depth; a spring at the Waterworks had a total hardness of 42·0, of which 12·2 was permanent; chlorine 4·07; reservoir holding 1½ day's supply; 350,000 gallons (constant); rateable value, 61,234*l.* 5*s.*; Local Government Act, 1858.

Mr. G. J. Symons,* F.R.S., calculates the mean annual rainfall at Cardington, at 106 feet above the sea, as:—

In 1850–9.	In 1860–9.	In 1870–9.
21·60	22·49	25·13

Buckingham.—*Acres*, 5000; population, 3585; ordinary wells (mostly supplied with pumps), and a few springs; rateable value, 18,922*l.*

* 'British Rainfall, 1880.'

River Ivel.

This tributary of the *OUSE* is 18 miles long. Chief places, Potton, Biggleswade, Caldicote, Baldock.

Baldock (Herts).—*Acres*, 141; population, 2326; wells in Chalk; rateable value, 5730*l.*

In 1834 the Rev. J. C. Clutterbuck recorded the sinking of a well a few miles north of Baldock; the gault was penetrated at 170 feet, and on the Lower Greensand being reached, the water rose to within 3 feet of the surface.

Hitchin.—*Acres*, 2078; population, 8434. A natural spring in the Chalk, in which it rises to a sufficient height to fall by gravitation for about three-fourths of a mile to the town, where the pipe enters two receiving reservoirs, whence the water is pumped to a third reservoir on the highest hill in the district. The quantity pumped daily at the supply reservoir is about 120,000 gallons, being 12,000 gallons per hour for 10 hours. Rateable value, 32,442*l.* Public Health Act, 1848. Rainfall in 1879, at 238 feet above Ordnance Datum, 29·13 inches; in 1880 it was 28·88 inches.

River Ouzel (tributary of the *OUSE*), 19 miles long. Chief places, Milton, Keynes, Fenny Stratford, Woburn, Leighton Buzzard.

River Tove (tributary of *OUSE*), 21 miles long. Grafton Regis, Towcester.

River Brook (tributary of *OUSE*), 10 miles long. Great and Little Shelford, Linton.

River Rhee (tributary of *OUSE*), 15 miles long. Edworth, Guilden Morden (Royston).

River Cam (tributary of the *OUSE*).

This river is 30 miles long.

Cambridge (23 feet above the sea).—Population, 35,372; water supply of private Company from tunnel in Chalk formation, at the base of the hills at Cherry Hinton, flows from the spring head through underground brick culvert, and then through iron pipes to the pumping station, where it is pumped to the top of the hill into two service (covered)

reservoirs, holding 1,500,000 gallons; varies from 500,000 to 800,000 gallons; rateable value, 139,902*l.*; 16 Vict. c. 23, 14th June, 1853; 18 Vict. c. 3, 26th April, 1855; 29 Vict. c. 81, 11th June, 1866; 34 Vict. c. 30, 25th May, 1871. The public supply is very pure, but of 25·1 hardness. Another supply is conveyed into the town by Hobson's Conduit, and supplies the fountain in the market-place. This is less pure, and of a hardness of 27·0. An artesian well, 200 feet, at Harston, yielded water of only 3·6 hardness and great purity.

Rainfall at the Waterworks, Cherryhinton, Cambridge, 35 feet above the sea, in 1876 was 23·62, in 1877 was 23·60, in 1878 was 21·29, in 1879 was 29·54, in 1880 was 23·02. The maximum monthly rainfall in 1876 was in September, in 1877 in August, in 1878 in November, all exceeding 4 inches. Observations made by Mr. H. Tomlinson, C.E.

Newmarket.—*Acres*, 740; population, 5160; private wells; rateable value, 22,533*l.* 3*s.* 9*d.*

Ely.—*Acres*, 16,566; population, 8172. The water supply is pumped out of the river *OUSE* into reservoir about 140 feet above the river, filtered; 242,000 gallons (I.) Rateable value, the whole district, 44,041*l.*, the town proper, 147,762*l.* The Public Health Act, 1848. Required an extension of the area available for filtration.

Mr. G. J. Symons,* F.R.S., calculates the mean annual rainfall at Stretham, near Ely, as:—

In 1860–9.	In 1870–9.
20·61	23·11

Saffron Walden (Essex).—Population, 6056. A well, sunk to the depth of upwards of 300 feet below the surface into a bed of chalk, and bored to the depth of 1004 feet. The principal supply comes from a bed of sand at about the depth of 300 feet. Two reservoirs of 240,000 gallons; 44,863 gallons, or 18·31 gallons per head (c.) Rateable value, 24,294*l.* 10*s.* Under the Joint Stock Companies Act, the Waterworks are carried on by a Company. Rainfall at Audley End in 1879, 28·49.

* 'British Rainfall, 1880.'

River Lark (tributary of the *OUSE*).

This stream is 28 miles long. Rainfall 26·6. Chief towns, Mildenhall (Newmarket), Bury St. Edmunds.

Bury St. Edmunds.—*Acres*, 2938; population, 16,211; chalk wells; 200,000 gallons (c); rateable value, 46,760*l.*; the works executed by Town Council under the Sanitary Acts. Rainfall in 1879, at Abbeygate Street, 29·14; in 1880, 25·13.

Mr. G. J. Symons, F.R.S., calculates the mean annual rainfall at Barton, as:—

In 1860–9.	In 1870–9.
23·68	25·71

Little Ouse or *River Brandon* (tributary of *OUSE*).

This river is 37 miles long; towns, Brandon, Thetford (East Harling), Botesdale. The whole of this basin is on the Chalk, much obscured by Alluvial and Glacial deposits. The river forms the boundary between the counties of Norfolk and Suffolk, west of the central watershed traversing these counties; eastward the line of division is continued along the River *Waveney*, the source of these two rivers, flowing in opposite directions, being but a very short distance from the watershed, and a few miles west of Diss.

Thetford.—*Acres*, 6460; population, 4034; constant supply; works finished in 1877; rateable value, 13,582*l.* 12*s.* 6*d.*; the Public Health Act, 1875.

WISSEY or STOKE (*LXXXVIII.*).

This river is 28 miles long, and has an area of 243 square miles.

Wells.—*Acres*, 2690; population, 2647; from wells; pumps; rateable value, 9828*l.* 2*s.* 6*d.*

Swaffham.—Population, 3643; from springs out of the Chalk, which are reached by sinking a well to the depth of about 180 feet, and then pumping by steam to a reservoir about 50 feet above the highest part of the town; from 20,000 to 30,000 gallons from 6 A.M. to 9 P.M.; rateable

value, 16,354*l.* 7*s.* 6*d.*; works made by a private Company, who obtained a grant from the lord of the manor.

NAR or SETCHY (LXXXVII.).

This river is 25 miles long, and 131 square miles area.

King's Lynn.—*Acres*, 2670; population (Municipal), 18,475; springs at Well Hall, in the parish of Gayton, and in the parish of Grimstone, Norfolk, seven miles distant from Lynn. The Waterworks have belonged to the Corporation for at least three centuries, have been several times reconstructed and improved, and the capital cost cannot consequently be stated. Filtered in passing from river to pumping reservoir; pumping by steam power to an 80-feet head; ramming into the mains, as well as pumping; from a reservoir at Lynn, supplied from the Gaywood and Grimstone brook, the source of which is at the springs before mentioned; about 1,000,000 gallons (c); rateable value, 55,200*l.* The King's Lynn Waterworks and Borough and Improvement Act, 1859. Desirable to take the water direct through iron pipes instead of from the open river.

Downham Market.—*Acres*, 853; population, 2631; pumps and wells on each person's property, which are erected and sunk by the owners of property; rateable value, 8374*l.* 17*s.* 6*d.* Rainfall in 1879 at Fincham, at 50 feet above the sea, 30·06; in 1880, 30·88.

Mr. G. J. Symons calculates the mean annual rainfall as:—

In 1860–9.	In 1870–9.
23·14	27·00

O.S. CATCHMENT BASIN LXXXVI.

The area of this basin is 293 square miles. The western half drains into the Wash, its coast-line extending from King's Lynn to Hunstanton, and bounded east by a watershed traversing the Chalk east of St. Edmund's Point. Parallel with the western coast-line extends a narrow belt of Oolites, succeeded by belts of Lower Greensand, Gault, Red Chalk, and Chalk.

The condition of the water at Sandringham House, the

Norfolk residence of His Royal Highness the Prince of Wales, was inquired into by the Rivers Pollution Commission in 1871, and all the waters obtained were pronounced unsafe and unfit for human consumption; the pump in the stable-yard, used for drinking, contained of solid impurity 29·60, of chlorine 5·80, a hardness of 14·9, of which 14·3 was permanent. The well supplying it was sunk in sand 20 feet resting on Carr Stone, and 14 feet below the floor of the offices; the water stood in it 6 feet, or 8 feet below that of the floor of the offices. The sand was evidently charged with surface soakage, and a new well into the lower water-bearing strata was recommended by the Commissioners, which they expected would be as good as the excellent water obtained at the Carrow Works, Norwich, 400 feet deep,* and the Times Paper Mill, Taverham, 150 feet deep. A constant supply of wholesome water has now been provided from a chalk spring, conveyed through 750 yards of earthenware pipe to a tank on a tower 60 feet high, giving ample fire-pressure; water has been laid on, in every cottage on the estate.

Hunstanton.—Mr. G. J. Symons, F.R.S., calculates the mean annual rainfall at the Hall, 60 feet above the sea, as:—

In 1860–9.	In 1870–9.
19·56	23·26

Cromer.—Messrs. S. V. Wood and F. H. Harmer state† that, though the coast of the north of Norfolk is deeply indented by deep valleys, an almost level floor of chalk extends along the base of the cliff where these valleys occur. The level of this floor at the western extremity of the coast section at Weybourne is a few feet above high-water mark, descending in 8 miles to low-water mark at Cromer, rising again to an arched boss 15 feet above the beach at Trimingham, after which it again sinks and disappears beneath the beach, its place being taken by the Pre-glacial Forest Bed as far as Hasborough, so that the Pre-glacial floor is entirely

* For details, see p. 165.

† 'Quarterly Journal Geological Society,' vol. xxxiii. p. 78. 1877.

unconnected with the existing valleys for at least 20 miles. The Cromer Valley is the deepest of these valleys, the Lighthouse Hill rising to a height of 248 feet; they are cut out of the Cromer Till and overlying Contorted Drift, which, with the pebbly sands underlying and interbedded with the base of the Cromer Till, forms the "Lower Glacial Series" of these authors. These beds are stated to have been denuded and eroded before the deposition of the sand and gravel of the Middle Glacial Age, which alike fills up troughs and caps hills of Contorted Drift. This interglacial denudation becomes more excessive in progressing southwards through Norfolk until the bottom of the valleys cut into the rock.

River Basins of England and Wales. Sea-coast from Dogger Head to Cromer. East Coast Streams. In Census 1871.

Counties.	Population.	Density. Acres to Persons.	Proportion of Population, probably living in this Group.	Population, about.
Lincoln	463,163	4·0	$\frac{3}{5}$	277,899
Rutland	22,070	4·0	$\frac{2}{3}$	14,714
Northampton	243,896	1·6	$\frac{19}{20}$	231,702
Leicester	268,764	1·9	$\frac{1}{10}$	26,876
Buckingham	175,870	2·5	$\frac{1}{3}$	58,623
Huntingdon	63,672	3·5	All	63,672
Cambridge	186,363	2·8	All	186,363
Norfolk	438,511	3·0	$\frac{1}{2}$	219,255
Suffolk	348,479	2·8	$\frac{1}{4}$	87,119
Essex	466,427	2·2	$\frac{1}{100}$	4,664
In Census 1881.				
Lincoln	469,994	3·7	$\frac{3}{5}$	381,998
Rutland	21,434	4·4	$\frac{2}{3}$	14,290
Northampton	272,254	2·3	$\frac{19}{20}$	258,642
Leicester	321,018	1·5	$\frac{1}{10}$	32,101
Buckingham	176,277	2·0	$\frac{1}{3}$	58,759
Huntingdon	59,614	3·8	All	59,614
Cambridge	185,475	1·7	All	185,475
Norfolk	444,825	3·0	$\frac{1}{2}$	222,412
Suffolk	356,863	2·6	$\frac{1}{4}$	89,213
Essex	575,930	1·5	$\frac{1}{100}$	5,759

CHAPTER VIII.

EAST ANGLIAN STREAMS.

RIVER BURE (*LXXXIX.*).

THIS river has a length of 45 miles; area, 348 square miles, of which 103 are occupied by Chalk and 245 by Tertiary deposits. Chief places, Rugby, Billockby, Cottishall, Aylsham.

The tributary River *Ant* is 7 miles long, with chief places, Horning, North Walsham.

From the point where the Forest Bed ceases east of Hasborough the district is low and flat, the valleys are but slight depressions, the Pre-glacial floor is not seen, and cliffs are entirely absent between Eccles and Winterton.

The valley of the *BURE* is of uniform structure; it is first cut out of the Contorted Drift only; as it deepens and widens, it cuts its way down first through the Lower Glacial pebbly gravel, the remnants of the Chillesford Clay ("Crag"), and then the Chalk; the latter about midway in the valley disappears, the base of the Contorted Drift sinking below the water-level east of a line drawn nearly north and south from a point 4 miles east of Norwich to the coast near Mundesley. This east and north-eastward dip of the Chalk floor allows the Lower Tertiaries to come in at Great Yarmouth, as proved in the well there. In the lower course of the *BURE* the Crag and Lower Glacial Beds are also carried down out of sight, and the valley is much below the level it occupied when the Forest growth of post-glacial age was living, now found beneath the alluvium.

The base of the Glacial series, in this district, is the "Bure Valley beds" of Messrs. Wood and Harmer, which beds are the "Westleton beds" of Professor Prestwich, and

underlie the Cromer Till. Mr. J. H. Blake * has recently proposed the following classification of the later Pliocene beds of North Norfolk, "The Rootlet-bed," the Chillesford Clay, and the Norwich Crag, and he embraces the three under the term "Mammalian, or Norwich Crag series."

The River *Ant*, tributary of the *BURE*, rising between Swafield and North Walsham, runs a similar course; the high ground is cut out of Contorted Drift, the surface of which has been extensively inter-glacially denuded near North Walsham, filled in with Middle Glacial gravels, and re-excavated by the river, which has cut down to a compact floor of Clay, probably Cromer Till.

North Walsham (Norfolk).—*Acres*, 4169; population, 2842; wells; rateable value, 13,355*l.* 5*s.* Rainfall at Worstead in 1879, 29·55; in 1880, 26·17 inches.

RIVER YARE (*XC.*).

The length of this river is 48 miles; area, with its tributaries, 880 square miles, of which 640 are Chalk and 240 Tertiary; rainfall, 22·4; chief places, Great Yarmouth, Limperton, Norwich, (Wyndham †). Tributaries, River *Waveney*, length 53 miles; chief places, Beccles, Bungay, Harleston, Horne, and Eye: River *Wensum*, length 43 miles; chief places, Hellesdon, Beepham, Foulsham, and Fakenham.

The valleys of the *YARE* and *Wensum* are cut through the Middle Glacial Drift, resting on the Contorted Drift, which locally thins out on either side of the *YARE* valley slopes, these gravels here resting directly on the Lower Glacial Pebbly Sands underlying the Contorted Drift. All these beds have been cut through by old fluviatile denudation, according to Messrs. S. V. Wood and Harmer, in interglacial times, and the valleys were then deeper than at present. To

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* Presidential Address, Norwich Geol. Soc., 1880.

† Names of localities in parentheses are situated within the river basin, but are not built on the main stream.

the east, "Plateau Gravels," and to the south-west Upper Glacial Deposit overlie the Middle Glacial. Following the *Wensum* down its course, it traverses a notch cut into the Chalk floor, which is overlaid by Upper and Middle Glacial Deposits and Contorted Drift; near Lyng Church, now Bintree Church, the Contorted Drift is thicker, and the modern alluvium is only slightly below the level of the chalky floor. Still lower down the valley, between Fakenham Church and East Barsham Railway cutting, the Contorted Drift is still thicker. Wells in the Middle Glacial prove 70 feet of it, but the Contorted Drift often rises through it, and appears on the highest ground.

The Pebbly Sands in this district have generally thinned out, and the Contorted Drift rests directly upon the Chalk, the base of which in these cases is a tough clay full of chalk *débris* near Norwich, and a greenish gritty deposit in the *Wensum* valley, but in one exposure the clay deposits overlie the sandy bed, with a layer of glaciated chalk intervening. Everywhere this bed rests on chalk which has been intensely glaciated, and, in fact, wherever in the Norfolk valleys the chalk has not been protected by a covering of Lower Glacial Sands, or Crag, its surface exhibits these phenomena, which change its ordinary porous character to a retentive water-sodden aspect, as at Bridgham, Roudham, and Croxton Heaths, between East Hasling and Thetford, where the Contorted Drift interglacially denuded is absent, and the later Middle Glacial Sand has been post-glacially denuded, and the chalk exposed.

Between the head of the *Wensum* valley and the sea the country consists of Contorted Drift, overlaid irregularly by Middle Glacial; a small stream flows 10 miles to the sea through the Contorted Drift, forming the Walsingham valley northwards. The latter is of great thickness, and consists of gritty white marl, which character it gradually assumes going westward along the coast section, the red brick earth of Central Norfolk being entirely replaced by it. The stream has cut a notch in the chalky floor, and a patch of

Middle Glacial occasionally occurs within the valley slope. These gravels are in still greater force in the *GLAVEN* valley, ascending to the tops of the valley, and descending the slopes; here also the river is cutting a notch in the chalk.

The *Tese*, affluent to the *YARE*, flows through a valley 12 miles in length, without including windings, cuts down to the Middle Glacial only in its upper extremity, but, at its lower end, to the Lower Glacial Pebbly Sands, the Crag, and the Chalk. The valleys are nearly entirely of interglacial * origin, the Contorted Drift having been entirely denuded, though probably in great strength in the country on either side of the valley, where it is hidden by the Upper Glacial Clay. The modern alluvium of the river is about level with the chalky floor; on it rest here and there patches left of Chillesford Beds and Fluvio-marine Crag.

In another affluent of the *YARE*, the *Ket*, falling into the river 8 miles west of Yarmouth, the Upper and Middle Glacial, the Contorted Drift, and the Lower Glacial Pebbly Sands are all alike in strong force, the latter forming great masses of shingle east of Loddon. The Chalk is not reached, and there is sufficient to show the valley was excavated subsequently to the Lower Glacial, and before or during the deposition of the Upper Glacial deposits.

The valley of the *Waveney* is supposed by Messrs. S. V. Wood, jun., and F. W. Harmer to have been the interglacial eastern extremity of a far longer valley, of which the *Little Ouse* formed the next portion westward, but which was excavated by a stream rising still further westward and northward, and flowing in a direction opposite to that of the existing *Little Ouse;* they consider this ancient river valley was occupied during the commencement of the Middle Glacial by land ice, which degraded away the Contorted

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* In taking this description of the sequence of events from Messrs. S. V. Wood and Harmer, I follow them in the use of the word "interglacial," as marking an episode, or change of condition; but I do not believe, with some geologists, that there was a very marked amelioration of climate in the midst of the Glacial Epoch.

Drift and other Lower Glacial deposits, which once must have overlaid the Fenlands, which they believe accounts for the abrupt termination of the Middle Glacial and Contorted Drift, a few miles west of the confluent source of the *Little Ouse* and *Waveney*. If this view cannot be substantiated, they think there is evidence to show the confluent valley must have formed a channel or strait as the land rose out of the Upper Glacial Sea, and that the tidal flow through it, like other East Anglian valleys, was the chief agent of re-excavation.

The late Mr. J. W. Flower* had previously, calling attention to the absence of high land, and the valley being traversed by streams flowing in opposite directions, and into different basins, stated his opinion that the valley was not due to existing streams. Messrs. Wood and Harmer think a wider trough than the *Waveney* valley, as it exists at present, was cut interglacially in the Contorted Drift, and the Upper and Middle Glacial deposited within it, and that the existing valley was excavated post-glacially in these latter deposits, as previously shown by Professor Prestwich† in his well-known section of the Hoxne bed of brick-earth with relics of Palæolithic man.

The lower part of the valley, instead of falling into the sea at Lowestoft, turns suddenly north-west to join the *YARE*, and is distinctly excavated in the Lower Glacial Beds. Near Aldeby Station the Middle Glacial rises to about 80 feet above Ordnance Datum, and occupies a hollow cut in the Contorted Drift and Lower Glacial beds. Upper Glacial Drift alike caps both the first two deposits. The alluvial plain of the *Waveney* is but little above the mean sea-level, while east of the river is the same succession; but at Corton Sea cliff, the commencement of another interglacial depression, pointing to a valley since destroyed by the sea, is observable, the succession being—post-Glacial Gravel,

* 'Quarterly Journal Geological Society,' vol. xxiii. p. 55.
† 'Phil. Trans. 1860,' part ii. p. 304.

Upper Glacial, Middle Glacial, and Contorted Drift, the surface of the latter being about 8 feet above the beach, or about 15 feet above datum.

Messrs. S. V. Wood, jun., and Harmer consider all the high ground of Central underlaid by the Contorted Drift as well as that of East Suffolk, but it is nearly everywhere concealed by the Upper Glacial, the Middle Glacial occurring as irregularly as it does over that part of the Contorted Drift of North Norfolk, where the Upper Glacial is not present. Troughs and valleys were excavated interglacially, and filled up and obliterated by the Middle and Upper Glacial deposits, since, in some cases, re-excavated out by modern denudation. The old south-eastern continuation of the *Waveney* has not been re-excavated. The Kessingland mammaliferous beds point to a pre-glacial land-surface below the Middle and Lower Glacial Sands and above the Chillesford Clay.

Great Yarmouth (Norfolk).—*Acres*, 3685; population, 46,211; a place called Ormesby Broad, being a series of inland lakes of about 600 acres, largely fed by springs; 267,700 gallons (c.); rateable value, 92,900*l.*; Great Yarmouth Waterworks Company's Acts, 1853, 1857, and 1869. Rainfall, 12 feet above the sea, in 1879, was 30·83; in 1880 was 24·79.

Eye (Suffolk).—*Acres*, 4324; population, 2296; from pumps, wells, and ponds only; rateable value, 10,902*l.* 7*s.* 6*d.*

Beccles (Suffolk).—*Acres*, 1783; population, 5721; partly by private waterworks, drawing water from a well, 91 feet deep, with borehole to 137 feet; the well and borehole have a separate set of pumps. The water is derived from sands of the Glacial Drift, and is turbid, but innocuous and wholesome; its hardness is 30 parts per 100,000. Supply partly by ordinary domestic wells, and perhaps in a few cases from the river; rateable value, 15,875*l.*; Beccles Waterworks Act.

Norwich.—*Acres*, 7400; population, 87,843; from the River *Wensum*, by the *Norwich Waterworks Company*; rateable value, 183,464*l.*; City of Norwich Waterworks Act, 1850. Hardness of water, 26·6, of which 5·3 is permanent;

chlorine, 3·10. A well in the Chalk at the Carrow Works, 400 feet deep, with boring to 1189 feet from the surface, of which 1147 was chalk, 6 feet Greensand, 36 feet of Gault, had a hardness of 29·7, of which 6·4 was permanent; chlorine, 2·58.

Mr. G. J. Symons,* F.R.S., calculates the mean annual rainfall at Honingham Hall, Norwich, 110 feet above the sea, was

In 1850–9.	In 1860–9.	In 1870–9.
25·99	23·98	27·31

Diss.—*Acres*, 3627; population, 3845; from wells only, which, with four exceptions, are situate on private property; rateable value, 12,007*l.* 10*s.*

East Dereham.—*Acres*, 4892; population, 5640; public and private wells and pumps only; scheme in preparation (constant); rateable value, 27,189*l.* 15*s.*

O.S. CATCHMENT BASIN XCI.

Area, 53 square miles, of which 3 are occupied by Chalk and 50 by Tertiary deposits. Rainfall, 23·2. Chief towns, Lowestoft, Stoven, Uggeshall.

Lowestoft (Suffolk).—*Acres*, 1673; population, 19,597; Lound Run, Suffolk, an inland lake (distant from Lowestoft about 6 miles), largely fed by springs; 156,000 gallons (c.); rateable value, 56,199*l.*; the Lowestoft Water, Gas, and Market Acts, 1853, 1857, 1863, 1877. Rainfall at Carlton Colville, in 1879, 30·18.

RIVER BLYTH (XCII.)

Length, 17 miles; area, 79 miles, of which 35 are on the Chalk and 44 Tertiary. Chief places, Southwold, Halesworth, Dunwich.

Southwold (Suffolk). — *Acres*, 647; population, 2111; wells; rateable value, 5772*l.* 15*s.*

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* 'British Rainfall, 1880. The Distribution of Rain over the British Isles.' By G. J. Symons, F.R.S. London: Edward Stanford, Charing Cross, S.W.

The *RIVER BLYTH*, like the *Waveney* and *YARE*, drains a tract of Upper and Middle Glacial, the Lower Glacial and Chillesford beds only showing in the valley, and chiefly on its northern slope. The Lower Glacial beds at Easton and Covehithe Cliffs consist of Pebbly Sands resting on the Chillesford Clay, the Contorted Drift having been removed.

RIVER MINSMERE (XCIII.).

Length, 11 miles; area, 34 square miles; of which 31 are Chalk, and 3 Tertiary. Chief places, Kelsale, Goxford, Lakefield.

RIVER ALDE (XCIV.).

24 miles, and 109 square miles, of which 28 miles are Chalk, and 81 Tertiary. Rainfall, 23·9. Chief places, Aldborough and Saxmundham. Its tributary the *Ore* is 9 miles in length; on it is the town of Framlingham.

O.S. CATCHMENT BASIN XCV.

Area, 32 square miles, the whole of which consists of Tertiary deposits. Chief places, Sudborne, Orford, Boyton.

RIVER DEBEN (XCVI.).

Length, 27 miles; area, 153 square miles, of which 95 are Chalk, and 58 Tertiary. Rainfall, 23·2. Chief places Woodbridge, Felixstow, Debenham. The River *DEBEN* valley is separated from that of the *ORWELL* by a tableland capped with Upper Glacial, but underlaid, according to Messrs. S. V. Wood and Harmer, by the Contorted Drift, in which these valleys are excavated, the actual junction being visible at Woodbridge and Hasketon; and there are also two other protrusions at Kirton and Trimley, discovered by Mr. Whitaker, of the Geological Survey. All these Middle Glacial protrusions consist of silts and tough blue brick-earth. A section through this tableland, passing through Kesgrove Church, shows the Lower Tertiaries rising to a height of 52 feet above Ordnance Datum, and in the

ORWELL valley, below Cauldwell Hall, sloping very gently east-north-east, overlaid conformably by about 20 feet of Red Crag cropping in a valley tributary to the *DEBEN*, near Sinkhouses, which is occasionally overlaid in the *ORWELL* valley by a few feet of Chillesford Beds. Over this is a sheet of Contorted Drift, worn here and there in troughs filled in with Middle Glacial, the deepest being marked by the existing valleys, where the base of the Middle Glacial rests on the Red Crag. In a well sunk 1 mile north of Seckford Hall, in the tableland lying between the valley of the *DEBEN*, at Woodbridge, and its tributary, the *Fain*, at Little Bealing, after penetrating 6 feet of Upper Glacial Clay and 51 feet of shelly gravel and buff sand (Middle Glacial), the Contorted Drift was found to be entirely cut out, and 6 feet of Red Crag with shells, and then a further 4 feet of Red Crag, was passed through, with water, resting on the Lower Tertiaries.

RIVER ORWELL (XCVII.).

Length, 16 miles; area, 171 square miles, of which 101 consist of Chalk, and 70 of Tertiary formations. Average rainfall, 22·5. Includes Needham, and the following Local Sanitary Authorities:—

Ipswich (Suffolk).—*Acres*, 8192; population, 50,762; partly from springs, hardness 28·2, of which 10·4 is permanent, and partly from artesian well in the Chalk, the hardness is 36·0, of which 12·3 is permanent; chlorine is 3·90, and the water good and palatable; reservoir holding 1,000,000 gallons; 800,000 gallons (constant); rateable value, 164,912*l.* 19*s.* 6*d.*; the Ipswich Waterworks Act, 1857.

Stowmarket (Suffolk).—Population, 4052; by wells sunk in the vicinity of the various dwelling-houses, good water being procured (constant); rateable value, 11,509*l.* 16*s.* 6*d.*

RIVER STOUR (CXXIX.).

Length, 45 miles;* area, with tributaries, 407 square miles, of which 200 are occupied by Chalk, and 207 by

Tertiary deposits. Rainfall, 23·9. Chief places, Harwich, Manningtree, Sudbury, Long Milford, Clare, Haverhill, 179 feet. Tributaries:—The *Brett*, 20 miles long; chief places, Hadley, Bildeston, Lavenham, Brettenham: the *Boxford*, 6 miles long; chief places, Boxford and Acton.

Haverhill (Suffolk).—*Acres*, 2381; population, 3685; land spring wells, from 20 to 50 feet deep (constant); rateable value, 7211*l.* 17*s.* 6*d.* in April 1878.

Sudbury.—Population, 6584; public waterworks, artesian well in the Chalk; the water has a hardness of 32 to nearly 38 parts per 100,000; reservoir; about 70,000 gallons (constant); rateable value, 17,879*l.* 1*s.* 8*d.*

Hadleigh.—*Acres*, 4288; population, 3237; partly from wells (3 artesian wells, 2 public wells) and partly from springs in the hills lying on the east side of the town and flowing through it (constant); rateable value, 14,682*l.*

Harwich.—*Acres*, 1965; population, 7810; an artesian well in the Chalk,* with hardness of 50·7, and some organic impurity; a public pump, and rainwater; not sufficient; rateable value, 20,135*l.* A boring here has been carried through the Chalk to the Lower Carboniferous Slate.

In the tributary valleys of the *STOUR*, the *Brett*, and the *Boxford*, Messrs. Wood and Harmer describe the Middle Glacial as exposed in the side of the valleys by fluviatial denudation, while the tableland between is covered with Upper Glacial Clay. These deposits rest, according to the authors, on laminated brick-earth, the equivalent of the "Contorted Drift," and are, therefore, interglacial. In the *Brett* valley, the London Clay floor is exposed as far as Hadleigh, with some traces of the Red Crag, discovered by the Geological Survey. Mr. Whitaker, of the Geological Survey, has noticed impressions of shells in the sands overlying the so-called "eroded" surface of the Shelly Crag, and he alludes to the springs thrown out by the Crag supported by London Clay.

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* This well passed through 64 feet of Gravel and Tertiary deposits, and was carried 293 feet in the Chalk; in all 357 feet.

RIVER COLNE (CXXX.).

Length, 24 miles; area, 192 square miles, of which 35 are Chalk, and 157 Tertiary. Average rainfall, 22·4. Chief places, Great Clacton, Colchester, Halstead, Toppesfield.

HALSTEAD.—*Acres*, 640; population, 5804; (constant) artesian well, reservoir; about 40,000 gallons a day; rateable value, 10,170*l.* 5*s.*; Public Health Acts.

COLCHESTER.—*Acres*, 13,300; population, 28,395; springs from Gravel resting on London Clay, hardness, 53. Polluted. Artesian well in Chalk, overlaid by London Clay, 400 feet deep; hardness, 25·7; chlorine, 21·00; water polluted, and dipping-places; reservoir; intermittent; rateable value, 91,361*l.* 12*s.* 6*d.*; Public Local Act of 23rd June, 1808, 48 Geo. III. c. 107; that the Urban Sanitary Authorities should become owners is desirable.

O.S. CATCHMENT BASIN CXXXIII.

Area, 53 square miles, all of which are occupied by Tertiaries. Chief places, The Naze, Walton-le-Soken, Lower Clacton, Great Holland.

WALTON-ON-THE-NAZE.—*Acres*, 2146; population, 1376 in the winter, 5000 in the full season; 1, private wells; 2, rain-water tanks; 3, pump on Mr. Walford's farm, "The Ashes," who sells water by the butt; 4, water sold in pailfuls by the adjoining parish of Kirby; rateable value, 7469*l.*

O.S. CATCHMENT BASIN CXXXII.

Area, 24 square miles, all of which are occupied by Tertiary deposits. Chief places, West Mersey, Langenhoe, Peldon.

RIVER BLACKWATER (CXXXI.).

Length, 6 miles; area, with its tributaries, 434 square miles, of which 24 miles are occupied by Chalk, and 410 by Tertiaries. Rainfall 19·3. Chief places, Maldon, Wickham Bishops, Witham, and Braintree. Tributaries:—

River *Pant*, 28 miles long, Coggeshall, Shalford, Radwinter: River *Chelmer*, 29 miles long—towns, Chelmsford, Dunmow, Thaxted, Gatestone: River *Ter* (tributary of *Chelmer*), 12 miles long; towns on it—Terling, Felstead. Urban Sanitary Authorities.

Braintree (Essex).—*Acres*, 2282; population, 5182; the Chalk lying under the London Clay; artesian well, 430 feet deep, sunk into the Lower London Tertiaries and Chalk, beneath the London clay. The water rises to within 40 feet of the surface; it has a hardness of 13·7, of which 5·0 is permanent; a total solid impurity of no less than 106·70, and contains 38·80 parts per 100,000 of chlorine; the water is pumped into a tank, holding 45,000 gallons, at the top of a high service tower, 200 feet high; varies materially, say 100,000 gallons (constant); rateable value, 14,300*l.*; the Public Health Act, 1848. Mr. G. J. Symons,* F.R.S., calculates the mean annual rainfall at Bocking, near Braintree, 200 feet above the sea, as:—

In 1860–9.	In 1870–9.
23·98	26·20

Messrs. S. V. Wood and Harmer consider the escarpment of London Clay, forming the eastern side of the middle portion of the valley of the *BLACKWATER*, as forming part of the concentric curved escarpments, to which the Chalk escarpment extending from the Chilterns to Cambridge belongs, and formed at one period, by the same disturbance. The Upper Glacial Clay in one of these lies up to the Chalk escarpment, and in parts of Bedfordshire, the Middle Glacial also, and the authors believe the *BLACKWATER* valley, or at least this portion of it, is pre-Glacial. At Witham Railway Station, a well, some years ago, proved a bed of blue clay, full of Chalk *débris*, to underlie the Middle Glacial Gravel.

Chelmsford.—*Acres*, 2840; population, 9885; an arte-

* 'British Rainfall, 1880.' London, 1881.

sian well and a spring called Burgess Well; collected into a reservoir, thence pumped into places required; about 120,000 gallons (intermittent); rateable value, 34,847*l.*; Public Health Act, 1848, and Local Government Act, 1858.

Maldon.—*Acres*, 3035; population, 5476; works of the *Maldon Water Supply Company* (*Limited*); reservoir (constant supply); from 40,000 to 50,000 gallons, 3 to 6 hours; rateable value, 17,135*l.*; the Companies Act, 1862.

Witham.—*Acres*, 3633; population, 2976; an artesian well yielding about 30 gallons and a supply from a spring about 60 gallons a minute; a water-tower, into which is pumped the water from a reservoir and from the artesian well; 10 hours daily; rateable value, 13,354*l.*; the Public Health Act, 1848; the Local Government Act, 1858.

The highest elevation attained by the Middle Glacial in East Anglia is about 360 feet at Danbury, in Essex. The average limit is between 200 and 250 feet; the Upper Glacial overlapping it, and resting directly on the older formation. The section in Middlesex at Finchley is a little above 300 feet, and Mr. Penning* makes this the limit of submergence during Middle Glacial times. Messrs. S. V. Wood and Harmer consider this explanation of its distribution difficult to understand, looking to its absence in many low tracts within the area of its occurrence, and its absence over a wider area, including the counties of Cambridge, Lincoln, Northampton, Leicester, Rutland, Bedford, and Huntingdon, often at very low elevation. These authors believe that, after the formation of the Contorted Drift, the country became dry land, during which valley excavation went on; this, however, is disputed.

RIVER CROUCH (CXXXV.).

Length, 15 miles; area, 181 square miles, all of which are occupied by Tertiary deposits. Average rainfall 23·5. Chief places, Southend, Rochford, Rayleigh, Billericay.

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* 'Quarterly Journal Geological Society,' vol. xxxii. p. 194.

Dr. Mitchell,* in a paper on the wells of the Essex London Clay, states wells at the following places overflow, and yield from 1 to 8 gallons per minute:—

	Average Depth in Feet.		Average Depth in Feet.
Foulness Island	450	Woodham	350
Mirsea and adjacent islands	300	N. Ockenden	80
Wallis Island	400	Fobbing	100
Little Wigborough	250	Bulpham Fen	80

RIVER RODING (CXXXIV.).

Length, 33 miles; area, 317 square miles, all of which are situated on Tertiary formations. Average rainfall, 27·1. Chief places, West Ham, Little Ilford, Woodford, Epping, Chipping Ongar. On a tributary are Dagenham, Romford, and Havering; on a second are Rainham, Upminster, and Brentwood; on a third, Purfleet, West Thurrock, and Tilbury.

West Ham (Essex).—*Acres*, 4774; population, 128,692; *East London Water Company*, part of Metropolitan system; rateable value, 367,227*l.* 10*s.*

Woodford.—*Acres*, 2148; population, 7142; the *East London Waterworks Company* (Rivers *THAMES* and *Lea*); a reservoir for storage (intermittent); rateable value, 35,000*l.*

Romford.—*Acres*, 1159; population, 6861. The *South Essex Waterworks Company's* mains are laid throughout the district, and the Company supplies water to the Local Board for watering roads, &c., and to some of the inhabitants. There are, however, a great number of wells and pumps; these are in Gravel, resting on London Clay; the hardness is about 50, and the water is polluted; mains; rateable value, 27,716*l.*

Southend.—*Acres*, 3441; population, 8064; Waterworks Company (constant supply); rateable value, 27,787*l.*

Leyton (Essex). — Population, 25,405; *East London Waterworks;* reservoirs at Lea Bridge, and thence by pipes; rateable value, 59,425*l.*

* 'Proc. Geol. Soc.' vol. iii. p. 131.

WALTHAMSTOW.—*Acres*, 4472; population, 21,697; partly from the *East London Waterworks Company* and partly from private wells; the *East London Waterworks* supply is by reservoir and filtered (constant and intermittent); rateable value, 71,384*l.*

WANSTEAD.—*Acres*, 2004; population, 4448; the *East London Waterworks Company;* supply intermittent and inadequate; rateable value, 28,720*l.* 10*s.*

The springs discovered in deepening the chalk pits at Grays Thurrock, in Essex, are said to be capable of yielding 10,000,000 gallons daily; when undisturbed, they rise to a height of from 4 to 8 feet above Ordnance Datum, lowering 12 feet after a week's pumping; 1,000,000 gallons used at Brentwood, Romford, and Warley barracks are yielded by a small well 6 feet in diameter, without interfering with the water-level in the adjacent pits.

The Rivers Pollution Commission reports the water from the open shaft, at Grays, of the *South Essex Water Company* as containing of solid impurity 44·80, a hardness of 29·4, of which 8·7 was permanent, and a temperature of 10°·8 Cent. The Grays well contained of solid impurity 41·74, and a permanent hardness of 7·4, and a temperature of 8°·8 Cent.

The artesian well at Epping, in the Chalk, contained 64·88 of solid impurity, 6·20 of chlorine, and a hardness of only 0·9, of which the whole is permanent. The Commissioners point out that the alteration chalk water undergoes in passing beneath the Tertiaries reaches here its furthest limit. The total solid impurity augments, the nitrogen as nitrates either diminishes or disappears, a considerable amount of ammonia makes its appearance, and the hardness is often nearly obliterated, bicarbonates of lime being replaced by bicarbonates of soda, of which the Epping sample contains 35½ parts in 100,000, and the water is as soft as the water of Loch Katrine.

CHAPTER IX.

THE THAMES BASIN.

A GLANCE at a geological map on which the watersheds are traced shows the southern limit of the *THAMES* basin, following, not as might be supposed, the well-marked ridge of the North Downs, but the central anticlinal axis of the so-called Weald Valley, to the upward thrust of which both watershed and surrounding valley alike owe their initial origin. Westward again, we find the watershed running from Selborne to Marlborough, along a line coinciding with the axis of movement that has thrust into sight the Greensands of the Vale of Pewsey; and it is worthy of note that this natural line closely corresponds to the boundary between the counties of Berks, Surrey, and Kent, on the one side, and Wilts, Hants, and Sussex on the other; a fact of great importance, to those who are anxious that watershed areas should be as far as possible coincident with County Boards in any scheme of national water supply.

From Marlborough Downs to Cheltenham the watershed takes leave of the Cretaceous rocks, and crosses the strike of the Oolite from top to bottom; it descends to a level averaging 350 feet above the sea, and advantage is taken of these two levels by the two lines of the Great Western Railway, and the *THAMES* and *SEVERN* Canal, which crosses the watershed at an elevation of 376 feet. Northward from this point it rises rapidly, and follows the crest of the Cotswolds, 1000 feet above the sea, on whose eastern flank the various sources of the *THAMES* take their rise, at points only 6 and 8 miles from the mouth of the *SEVERN* at Gloucester.

The water-parting running along the Cotswolds forms part

of an important watershed which crosses England diagonally from south-west to north-east, separating the basins of the *SEVERN, TRENT,* &c., on one side, from those of the *THAMES* east coast streams, *WITHAM,* and *OUSE* on the other. This line nearly separates all the strata up to the Trias on the west from the strata lying above the Lias on the east. Commencing on the Chalk Downs of the Isle of Purbeck, it ranges by Crewkerne, Warminster, and Devizes; where at Roundway Downs the southern *THAMES* watershed terminates against it, after separating the head waters of the *Kennet,* from those about to flow through the Vale of Pewsey and over the Salisbury Plain.

From Roundway and Marlborough Downs to Daventry the diagonal watershed forms the western boundary of the *THAMES* Basin, separating it from that of the *SEVERN* and its tributaries, the *Lower* and *Upper Avon.* Gradually traversing somewhat lower Oolitic beds resting on the Lias from Chipping Campden, by Naseby, to Oakham, thence traversing the Oolites overhanging the Vales of Catmos and Belvoir, where it again crosses the Lias, and reaches the Red Marls at Gainsborough, separating the *TRENT* from the *WITHAM,* at an elevation of only a few feet above the sea.

Following the northern watershed of the *THAMES* valley from the point where it commences at the diagonal watershed near Weedon, at the base of the Oolites, it cuts across the strike of these rocks, and the overlying Lower Cretaceous strata overlooking the Vale of Aylesbury, to the Chalk at Tring, from which point it turns abruptly, and follows the strike of the Chalk escarpment by Hitchin, Royston, and Newmarket. The unimportant part the North and South Downs escarpments play in defining watersheds will be hereafter noticed. The great Cretaceous escarpment traversing England from the Dorsetshire Downs to the Norfolk Wash has nearly as little hydrographical influence. At Blandford it is breached by the *STOUR,* and though the great diagonal watershed runs along its crest from Wincanton to

Marlborough Downs, a distance of 40 miles, it again leaves it, sweeping westwards across the strike of the Oolites to the top of the Lias above Cheltenham; while the Chalk escarpment overhangs the Vale of the White Horse, and runs right across the *THAMES* valley to Tring, the *THAMES* breaching the escarpment after the same fashion as the *STOUR*, forming a gorge two miles in width and 350 feet in depth. From Tring to Newmarket, a distance of 56 miles, the watershed again follows the Chalk escarpment. Northward and eastward from this, the water-parting passing through Central Norfolk and Suffolk trends eastward of the escarpment, which is thus again breached by streams, which, unlike the Dorset *STOUR* and the *THAMES*, are in this case flowing westward from the watershed, and up instead of down the dip of the strata.

Physically all the east coast streams must be considered as belonging to the *THAMES* Basin, but for convenience it is usual to consider the eastern boundary to be that of the minor watershed between the *Lea* and the *Roding*.

The *THAMES* Basin includes within its area 170 square miles of Lias, 931 of Oolites, 5 of Hastings Sands, 13 of Weald Clay, 453 of Greensand and Gault, 2096 of Chalk, and 945 of Tertiary deposits. The Chalk above Kingston occupies 1047 square miles, and has a storage capacity of 16 months, according to Mr. Beardmore, who estimates the annual rainfall run off at Kingston between 1850 and 1868 to give an annual mean rate of 7·83 inches, while the mean rainfall of Oxford was 26·08, the remainder being absorbed by vegetation or evaporated. The deep-seated springs in this formation maintain the dry-weather flow of the river, the minimum of which amounts to 350,000,000 gallons per diem, of which five London Water Companies have Parliamentary powers to draw 110,000,000 gallons, or nearly one-third. The Water Companies, however, do not take the maximum quantity to which they are entitled, but are rather increasing their supply by sinking wells to the Chalk, and obtaining water free from organic impurity.

Lower Thames or Tertiary Basin.

The river runs entirely through Tertiary formations. Its northern tributaries rise in the Chalk Downs forming the eastern prolongation of the Chiltern Hills; its southern tributaries breach the escarpment of the North Downs, and rise in the Weald of Kent.

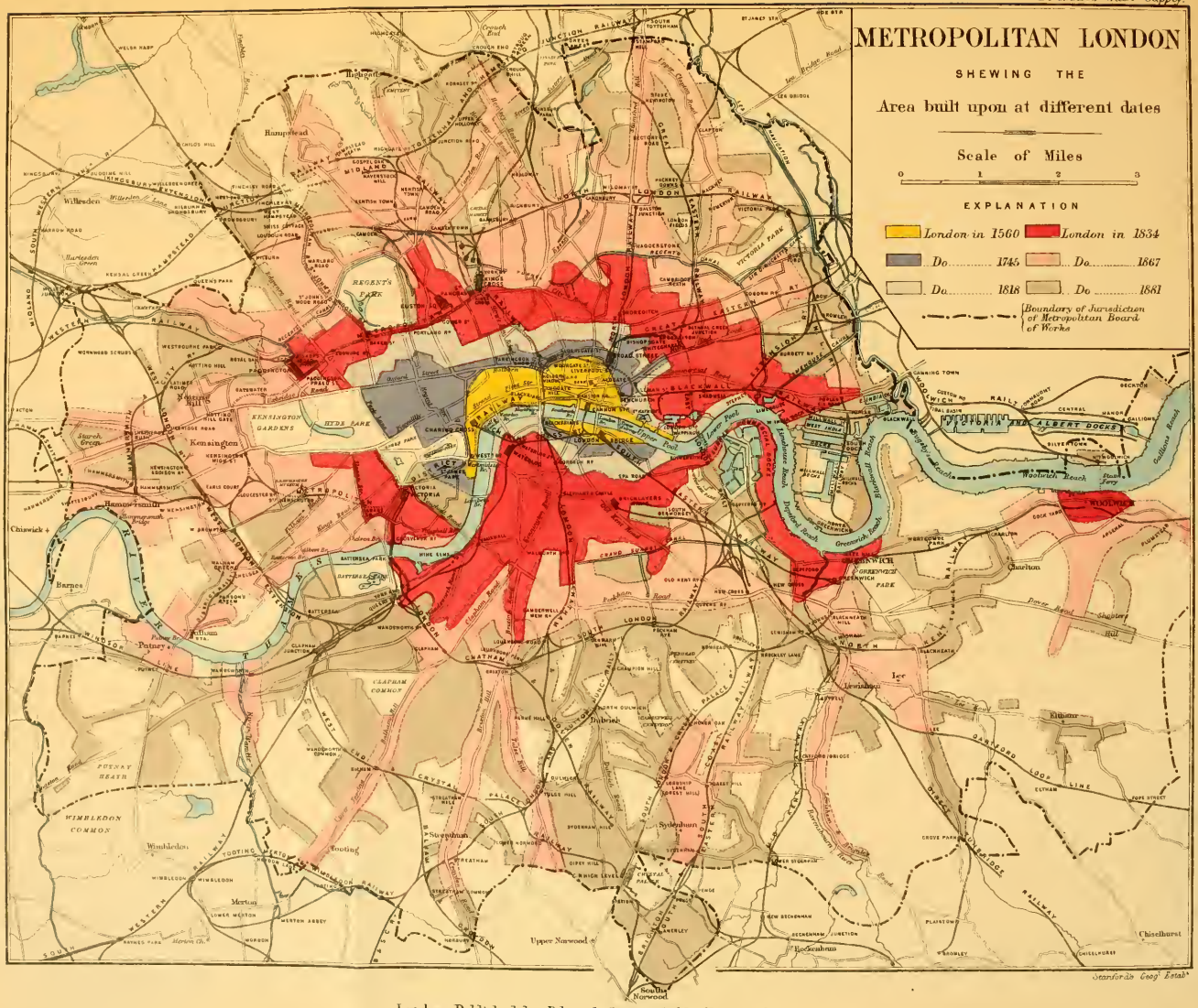
It appears to be the fate of great rivers to be subject to change of masters at different periods of time, like the inhabitants of their banks, and to be sometimes governed by laws that cannot be considered to be of a character likely to improve their condition. Of no river, probably, is this more true than of the *THAMES;* for, except we go back to the time when the pre-Aryan Esquimaux broke the ice of the *THAMES* Valley with his Palæolithic chisels at the close of the Glacial Epoch, the river has never been free of control. In the days of William the Conqueror, the Mayor of London was definitely established as Conservator; and one of his successors, William Stondon, in the reign of Richard II., realized the evil of pollution in 1390, and ordered all injurious materials to be cleared from the banks between the Palace of Westminster and the Tower of London, and in future similar matter to be carried in boats out to the centre of the *THAMES* Channel, and emptied at ebb tide. The *THAMES* Conservancy in Henry VII.'s reign was considered of sufficient importance to need a Charter on the subject to be given by that King to the City of London, which Charter, printed by Caxton, was amongst the documents exhibited at the late Caxton Exhibition. The powers given under these and succeeding charters constituted the Lord Mayor and Commonalty Bailiffs or Conservators of the *THAMES* from Staines Bridge to Yantlet Creek, and in the River *MEDWAY.* These powers within their limits they exercised until 1859, when the *THAMES* Conservancy Board was formed by Parliament as the result of a compromise between the City of London and the Crown, the latter laying claim to the space between tide-marks on the foreshores of

the *THAMES*. The boundaries in this Act remain those over which the City held sway, *i.e.* from Staines Bridge to an imaginary line drawn from Yantlet Creek in Kent to the City Stone opposite to Canvey Island in Essex. In the preamble of the Bill the expediency of the regulation of a river being *under one uniform management* is stated, which principle is more strongly recognized in their Third Act, passed in 1866, which cancels the "Upper Navigation Act" of 1795, extinguishes most of its Commissioners, and gives its power to the Board, whose western limit of authority is thereby carried from Staines to Cricklade in Wilts. By this Act the Board have power to prevent pollution by the connection with the river of anything objectionable from Yantlet Creek to Cricklade, except that portion of the *THAMES* valley occupied by the Metropolis, and presided over by the Metropolitan Board of Works, who have power to pollute the river to any extent they choose, provided they clear away, at their own expense, to the satisfaction of the Conservancy Board, any banks that may accumulate.

By this Act also the Water Companies taking their supplies from the *THAMES*, in consideration of the advantages given them, contribute towards the expenses of the Board in preventing pollution.

By the Fourth Act, 1867, Fifth, 1870, and Sixth Act, 1878, the powers of the Conservancy Board are increased so as to include within their jurisdiction the country lying within 10 miles of the banks of the *THAMES*, and the six Water Companies, viz. *Chelsea, Lambeth, Grand Junction, Southwark, East London, and West Middlesex*, drawing from the *THAMES*, agree to pay an increased sum for liberty to draw a certain quantity of water from the *THAMES*, in consideration of the increased purity of the water.

From the annual reports of the Conservancy Board, published in the Parliamentary papers, we learn that the Court of Queen's Bench determined in 1861 they had no power over fisheries; that, in 1865, the *THAMES* Embankment had lessened the volume of the water without adding



London: Published by Edward Stanford, 55, Charing Cross.

compensation by dredging; that, in 1867, they issued notices to Oxford, Abingdon, Wallingford, Reading, Henley, Marlow, Cookham, Windsor, and Eton, requiring them to discontinue the flow of injurious matter into the river.

The burden of the succeeding reports, as to the Lower Navigation (Staines to Yantlet), is the steadily increasing size of the banks produced by the Metropolitan Board of Works, and the difficulty in causing the Authorities lying above the Board of Works, but below Staines, to prevent pollution of that portion of the river; while, as regards the upper portion of the river, the various towns have carried out the diversion of drainage required of them; and with few exceptions "all sewerage flowing into the river above the intake of the Water Companies has, so far as the Conservators have been able to discover, now been diverted from the river."

North Bank of the THAMES.

*London Water Supply,** from the River *THAMES.*—Professor Prestwich† has pointed out that the first settlement of London took place along the water-bearing alluvial gravels of the *THAMES* valley, the early growth, following unerringly the direction of the gravel, "eastward towards Bow, Whitechapel, and Stepney; north-eastward towards Hackney, Clapton, and Newington; and westward towards Kensington and Chelsea; while northward it came for many years to a sudden termination at Clerkenwell, Bloomsbury, Marylebone, Paddington, and Bayswater, for north of a line drawn from Bayswater, by the Great Western Station, Clarence Gate, Park Square, and along the north side of the New Road to Euston Square, Burton Crescent, and Mecklenburgh Square, this bed of gravel terminates abruptly, and the London Clay comes to the surface, and occupies all the ground to the north." The extension of Water Companies to the clay districts caused the existence of the town lying

* See also pp. 182, 194, 243, and 250.

† 'Quar. Jour. Geol. Soc.,' vol. xxviii. 1872. Anniversary Address of the President.

between Holloway, Camden Town, Regent's Park, St. John's Wood, Westbourne Park, and Notting Hill. The gravels were not only drawn in the numerous shallow wells, but the springs issuing where the gravels had been cut down by shallow valleys to the London Clay below, were in great repute, as Bagnigge Wells, Holywell, Clerkenwell, St. Chad's Well, and others.

The first systematic waterworks supply was carried out by an ingenious Dutchman named Peter Morrys, who pumped the *THAMES* direct at London Bridge in 1581. In 1613 Sir Hugh Myddelton brought the *New River* to London, and in 1723 the *Chelsea Waterworks* were established, followed by the *Lambeth* in 1785, the *West Middlesex* in 1806, and the *Grand Junction* in 1820, all taking their supplies of water from the *THAMES*. Iron pipes, in lieu of wooden ones, were introduced at the end of the last century, and the process of filtration in 1829 by the *Chelsea Company*. The establishment of these various works, rendering it possible to distribute water at any point in the Metropolis, removed the cause of the restriction of the growth of London to the area covered by gravel, and London at once spread over the clay area.

The quality of the water supplied has been the subject of repeated and elaborate investigation. In 1828, a Royal Commission, consisting of Mr. Telford, C.E., Dr. Brande, F.R.S., and Dr. Roget, F.R.S., was appointed. They recommend filtration, but point out that it only gives a partial purification. In 1848 and 1849, London was again visited by epidemic cholera, and Dr. Snow, in August, enunciated the doctrine, since admitted by all, that cholera is spread by drinking water containing cholera germs derived from cholera patients. In 1848, the *Lambeth Company* obtained an Act authorizing them to remove their intake from Lambeth to Thames Ditton. In May, 1850, the General Board of Health (consisting of the Earl of Carlisle, Lord Ashley, Edwin Chadwick, Esq., and Dr. Southwood Smith), issued a report, in which they state that four companies out of seven

deliver unfiltered water, all water above the hardness of that supplied to most towns; that intermittent distribution and sewage pollution are general; that, aided by the Ordnance Geological Survey Department,* they have examined sites for a suitable source of supply, and found one 150 square miles in extent.

Parliament was still unwilling to legislate, and a Royal Commission was appointed in 1851, consisting of the late Professor Graham, F.R.S., the late Dr. W. Allen Miller, F.R.S., and Dr. A. W. Hoffmann, F.R.S., to report on the chemical quality of the water supplied, and that proposed to be supplied. They state that the hardness of the *THAMES* water causes a considerable loss of soap in washing, and regard the *THAMES* as the main drain, even above Kingston, of a large and populous district. This evidence of the unfitness of the water of the *THAMES*, with the frightful cholera mortality in 1849, made so deep an impression on the public mind, that the Government introduced a Bill in 1851 for the amalgamation of all the Companies, with a compulsory clause giving power to the Secretary of State to prescribe the source from which the water should be obtained.†

This Bill was lost by the opposition of the Companies, and a compromise effected, and an Act received the Royal Assent, 1st July, 1852. By it no Company can take water from the tidal portion of the *THAMES* below Teddington Lock, and all storage reservoirs and aqueducts conveying

* Now the Geological Survey of the United Kingdom, forming part of the Science and Art Department.

† Cost of Filtration of London Water, given before the Committee of the Metropolitan Water Bill, 1851-52.

Name of Water Company.	Authority.	Cost of Filtration.
New River	Mr. W. C. Mylne ..	·43*d.* for 1000 gallons.
Southwark and Vauxhall	Mr. Joseph Quick ..	$\frac{1}{8}$*d.* ,,
Grand Junction	Mr. Hawksley	$\frac{1}{8}$*d.* ,,

water not afterwards to be filtered must be covered within a radius of 5 miles from St. Paul's. High pressure to be given when demanded by four-fifths of the inhabitants. All the Companies then removed their works to above Teddington Lock. The *East London Company* removed its works in 1852 from the *Lea* to 9 miles up the stream at Ponder's End, above tidal inflow, and the *Kent Company* abandoned the polluted *Ravensbourne;* with the result of the death-rate being decidedly lower, though still not altogether satisfactory, the population having so increased that, of every 1000 inhabitants in the world, four are believed to live in London.

London Water Supply.—Artesian Wells.*

The *Southwark and Vauxhall Waterworks* † supply-district, occupies the area lying between the *Lambeth Waterworks* boundary and the *THAMES*, having a frontage on that river from a mile and a half north of Kingston, and eastward into Kent. Their pumping station is at Hampton, on the *north* of the *THAMES*, west of *Cardinal's River*, and close to the pumping station of the *Grand Junction* and *West Middlesex Companies;* the main crosses the *THAMES* to its supply-district, north of Richmond Bridge, thence by East Sheen, Putney, Wandsworth, Battersea, to the reservoirs and works near Battersea Park and Chelsea Bridge.

The *West Middlesex Waterworks* supply-mains, run parallel to those of the *Southwark* and *Vauxhall* as far as Mortlake, thence they pass northwards through Barnes, along the *THAMES* bank, recrossing the *THAMES* west of Hammersmith Bridge, the reservoirs and works being on the south side of the river. There are also works on the north, from which a main runs by Uxbridge, Campden Hill, Edgware Road, crossing the Regent's Canal, to a reservoir at Primrose Hill. From the head of the Serpentine to the Regent's Canal it traverses the *Grand Junction Waterworks* area from the Canal to Primrose Hill, re-enters that of the *West*

* See also pp. 179, 194, 243, and 250.

† For Statistics of this and other London Water Companies, see Table, p. 185.

Middlesex, including the Regent's Park district, Willesden, population 27,397, and Hendon, population 10,484, and southwards to the Great Western Railway and Oxford Street.

Grand Junction Waterworks.—The main runs parallel to the two Companies already described as far as Twickenham, keeping entirely on the north side of the river, thence it runs by Isleworth, Brentford (east of which are the works and reservoir), Hammersmith, to Campden Hill, where there are further works and a reservoir. Its district of supply comprises Hampton, population 13,538, Bushey, Teddington, Twickenham, population 12,479, Hounslow, Isleworth, population 22,717, Brentford, population 4869, Hanwell, Ealing, Acton, population 22,859, and London north of Uxbridge Road, south of the Great Western Railway, and west of Edgware Road, and a small tract between Oxford Street and St. James's Park, Park Lane, and St. Martin's Lane.

The Royal Commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers, stated their decided opinion that the rivers *THAMES* and *Lea* should be given up as early as possible as a source of water supply for London, regarding the condition of these rivers as hopeless, and they advocate the adoption of deep well and spring water from the Chalk and Upper Greensand above the Gault, as a substitute for the existing supply; and they state that, within 30 miles radius of London, there is an area of 849 square miles occupied by these formations, while a 40 miles' radius enlarges the area to 1597 square miles. Within 50 miles, excluding the Chalk beds in the neighbourhood of Brighton, it is no less than 2150 square miles. Of these several areas, 635½, 1296, and 1668¼ square miles respectively are on the north side of the London Clay, and 213¼, 301, and 482 on the south side.

Guided by experiments, carried out for many years by Dr. J. Evans, F.R.S., past President of the Geological Society, and by Mr. C. Greaves, M. Inst. C.E., they estimate that the amount of rainfall which sinks into these porous and permeable rocks amounts to 6 inches annually, and

they point out that this amount of infiltration into the Chalk alone in the 30 miles radius would give a daily theoretical maximum supply of 202,000,000 gallons available for the Metropolis.

They admit that, if this water be artificially abstracted by a number of wells sunk below the level of the present spring heads of the district, the water taken will be at the expense of the streams which now flow through the valleys of the Chalk area; but they appear, as pointed out by Dr. Evans, not to have realized what would be the effect of producing underground storage for the reception of unusual rainfalls below the level of the springs in which the drainage of the district would usually escape, over an area entirely dependent on its surface drainage for the sustenance of the rich agricultural produce upon it, and for the motive power which drives the water-mills which stud the streams of the district.

Exclusive of 8,000,000 gallons of deep-well water supplied to London by the *Kent Company*, the daily quantity of water delivered to London is no less than 121,654,961 gallons. If the absorption of 6 inches of rainfall over an area of 849 square miles yield, as the Commissioners calculate, 202 million gallons, it is clear that it will require more than three-fifths of that area to yield the quantity at present supplied to London.

The exact area requisite at 6 inches absorption being 541 square miles, Dr. Evans states that, so far from the 6 inches being constant as supposed in the calculation, in some years the quantity of rainfall which percolates to a depth of only 3 feet in the soil is as low as 3 inches, and even for three years running Dr. Evans found the percolation through 3 feet of ordinary soil covered with vegetation to have been only on an average $3\frac{1}{2}$ inches, and through chalk under the same conditions less than $5\frac{1}{4}$ inches, so that the area which would have to be exhausted is considerably larger than that estimated by the Commissioners, being not less than 800 square miles at 4 inches of percolation.

In 1877, the Metropolitan Board of Works requested Sir F. Bramwell and Mr. Edward Easton to report on the

London. Published by Edward Stanford, 55, Charing Cross.

REGISTRATION — LONDON.

THE "INNER LONDON" OF THE REGISTRAR GENERAL'S WEEKLY RETURN.

NOTE.—The Figures prefixed to the names of Sub-districts correspond to the Figures on the Map. The Districts are named on the Map.

MIDDLESEX.

I—KENSINGTON.

1.	St. Mary, Paddington ..	69,785
2.	St. John, " ..	37,313
3.	Kensington Town ..	120,127
4.	Brompton	42,797

II—FULHAM.

1.	St. Peter, Hammersmith	7,596
2.	St. Paul, "	64,320
3.	Fulham	42,895

III—CHELSEA.

1.	Chelsea South	30,395
2.	" North West ..	24,923
3.	" " East ..	32,783

IV—ST. GEORGE, HANOVER SQ.

1.	Hanover Square	16,858
2.	Mayfair	13,481
3.	Belgrave	59,178
4.	St. John, Westminster ..	35,482
5.	St. Margaret, " ..	24,604

V—WESTMINSTER.

1.	Golden Square	11,585
2.	Berwick Street	18,280
3.	St. Anne, Soho	16,591

VI—MARYLEBONE.

1.	All Souls	26,758
2.	Cavendish Square ..	14,893
3.	Rectory	24,992
4.	St. Mary	21,122
5.	Christ Church	33,691
6.	St. John	33,640

VII—HAMPSTEAD.

1.	Hampstead	45,436

VIII—PANCRAS.

1.	Regent's Park	39,103
2.	Tottenham Court ..	27,728
3.	Gray's Inn Lane	30,229
4.	Somers Town	34,355
5.	Camden " ..	17,406
6.	Kentish " ..	87,388

IX—ISLINGTON.

1.	Islington, West	122,374
2.	" East ..	161,254

X—HACKNEY.

1.	Stoke Newington ..	22,780
2.	Stamford Hill	9,256
3.	West Hackney	37,600
4.	Hackney	76,886
5.	South Hackney	39,878

XI—ST. GILES.

1.	St. George, Bloomsbury	16,662
2.	St. Giles, South	14,862
3.	" North	13,733

XII—STRAND.

1.	St. Martin-in-the-Fields	17,447
2.	St. Mary-le-Strand ..	7,520
3.	St. Clement Danes ..	8,547

XIII—HOLBORN.

1.	St. George-the-Martyr ..	18,630
2.	St. Andrew, Eastern ..	10,706
3.	Saffron Hill	6,514
4.	St. James, Clerkenwell ..	17,516
5.	Amwell	19,261
6.	Pentonville	14,736
7.	Goswell Street	17,506
8.	Old Street	11,541
9.	City Road	18,626
10.	Whitecross Street ..	9,217
11.	Finsbury	7,463

XIV—LONDON CITY.

1.	St. Botolph	11,168
2.	Cripplegate	7,185
3.	St. Sepulchre	3,352
4.	St. Bride	8,383
5.	Castle Baynard	9,047
6.	Allhallows, Barking ..	3,619
7.	Broad Street	3,652

SURREY.

XXII—ST. SAVIOUR, SOUTHWARK.

1.	Christchurch, Southwark	13,656
2.	St. Saviour	14,972
3.	Kent Road	21,383
4.	Borough Road	15,951
5.	London Road	21,318
6.	Trinity, Newington ..	26,647
7.	St. Peter, Walworth ..	59,562
8.	St. Mary, Newington ..	21,622

XXIII—ST. OLAVE, SOUTHWARK.

1.	St. Olave, Southwark ..	3,047
2.	St. John, Horsleydown ..	8,927

ST. OLAVE—*continued.*

3.	Leather Market	16,271
4.	St Mary Magdalen ..	15,669
5.	St James, Bermondsey	54,662
6.	Rotherhithe	36,010

XXIV—LAMBETH.

1.	Waterloo Road, First ..	15,171
2.	" " Second	16,346
3.	Lambeth Church, First	19,876
4.	" Second	39,822
5.	Kennington, First ..	45,225
6.	" Second ..	35,295
7.	Brixton	62,817
8.	Norwood	19,017

XXV—WANDSWORTH.

1.	Clapham	36,378
2.	Battersea	107,248
3.	Wandsworth	28,005
4.	Putney	13,221
5.	Streatham	23,545

XXVI—CAMBERWELL.

1.	Dulwich	5,590
2.	Camberwell	59,090
3.	Peckham	71,065
4.	St. George	50,810

KENT.

XXVII—GREENWICH.

1.	St. Paul, Deptford ..	76,740
2.	St. Nicholas " ..	7,901
3.	Greenwich, West ..	22,019
4.	" East ..	24,604

XXVIII—LEWISHAM.

1.	Eltham	5,827
2.	Lee	21,558
3.	Lewisham Village ..	19,859
4.	Sydenham	26,070

XXIX—WOOLWICH.

1.	Charlton	10,930
2.	Woolwich Dockyard ..	17,650
3.	" Arsenal ..	18,050
4.	Plumstead, West ..	14,009
5.	" East ..	19,243

Total population of Registration London 3,814,571
Total population of Metropolitan London (which includes the Hamlet of Penge in the Superintendent Registrar's District of Croydon) 3,832,441

AVERAGE NUMBER of HOUSES, &c., supplied by the several LONDON WATER COMPANIES during the Year 1879. (Compiled from RETURNS furnished by COLONEL BOLTON to the SELECT COMMITTEE on LONDON WATER SUPPLY, 1880.)

WATER COMPANIES.	Average Number of Houses supplied.	Average Daily Supply of Water during the Year in				Supply from			Maintenance and Management per Million Gallons.	Water Rents per Million Gallons.
		Gallons.	Cubic Metres.	Gallons for Domestic Purposes (estimated).	Gallons for Domestic Purposes to each House Daily.	THAMES. Max. taken.	LEA. Max. taken.	Other Sources.		
Chelsea Water-works	29,057	8,254,683	37,135	6,702,126	236	9,000,000	..	..	11 19 8	30 [illegible] 7
Grand Junction	38,412	11,885,490	51,860	9,359,570	267	12,000,000	..	..	10 17 6	30 7 0
Lambeth	59,027	13,567,387	58,004	10,468,645	205	14,000,000	..	..	11 16 2	27 19 3
Southwark and Vauxhall ..	80,917	21,494,810	84,120	15,181,867	190	24,000,000	..	..	8 3 10	21 6 5
West Middlesex	50,835	9,861,469	43,310	7,816,515	170	11,000,000	..	..	15 16 3	43 1 8
East London ..	116,114	28,543,439	102,758	18,545,672	175	None	35,000,000	..	7 17 4	19 8 1
Kent	45,855	8,092,987	30,498	5,504,343	120	No powers	..	8,092,987	8 14 5	27 10 11
New River ..	126,902	27,957,583	121,066	21,849,857	179		22,000,000	12,500,000	14 0 5	36 18 6
Totals ..	547,119	129,657,848	528,751	95,428,595	187	70,000,000	57,000,000	20,592,987	..	..

NOTE.—According to returns of the London Water Companies made to the Select Committee on East London Water Bills (Session, 1867), it is estimated that during the year 1866, on an average, 82·18 per cent. of the total average daily supply of water for all purposes was for domestic use; the proportions supplied for the year 1866 have been applied in estimating the quantities for the year 1868, in column 4 (last but one). The average daily quantity was 99,892,311 gallons, 453,857 cubic metres, equal to about as many *tuns* by measure, *tons* by weight), of which 373,000 cubic metres were used for domestic purposes, as above 82·3 decalitres per house, or 11·6 decalitres per person (= 25·53 gallons). One decalitre equals 2·201 gallons. A cubic metre is equal in volume to 35·3166 cubic feet, or 220·0967 imperial gallons. It is nearly equivalent to the old English *tun* of four hogsheads, holding 35·248 cubic feet. It is in general use on the Continent; and its volume of water weighs a metric ton, differing but little from the common ton in use.

Water Supply of London, in conjunction with Sir Joseph Bazalgette, especially in relation to the quality of the potable water, and to the provision of water at an adequate pressure for the extinction of fires. They recommended that a new and separate supply of 16,000,000 gallons daily should be provided of pure spring water, to be used for drinking and cooking purposes, which they estimate at 2 gallons per head, and for the extinction of fires, sufficient pressure being provided, by storing the water in four reservoirs north and south of London, at an elevation of 400 feet above Ordnance Datum, supplied by pumping engines drawing their water from points 8 to 15 miles distant from the reservoirs. These proposals were afterwards embodied in a Bill laid before the House of Commons by the Metropolitan Board, which, not being supported by the Government of the day, fell through, as did a proposal of that Government to purchase the water companies, and constitute a new Water Trust, which was thrown out by Parliament.

A longitudinal section drawn through London discloses a concealed ridge of ancient Palæozoic rock, overlaid by various Tertiary and Secondary formations arranged in a synclinal curve, the centre of which nearly corresponds to the line of the River *THAMES* and the position of the Metropolis, and which appears to be nearly coincident with the ridge line of the concealed Palæozoic, against which some of the older Secondary rocks thin out.

The order of succession of rocks being as follows:—On the north side an outlier of Bagshot Sands occurs on Hampstead Heath, and is underlaid by the London Clay, which, spreading over the greater part of the Lower *THAMES* Valley, rests on the south side of the basin on the *Thanet Sands*,* and on the north side directly on 640 feet of

* The Thanet Sands were so named by Professor Prestwich, from their being well developed in the Isle of Thanet. They are of marine origin, and are represented in the Paris Basin by the Sands of Bracheux and Abbecourt; in Belgium, by the "Système Londénien." They occur at Purfleet and Grays, Essex, but thin out west of London.

Chalk. On the south side of the synclinal the Chalk thins somewhat: the Upper Greensand alone occurs here, thinning out against the Palæozoic ridge, which northward is overlaid, first by the Gault, and still further north by the Lower Greensand, and probably also by the Oolitic Clays. Similarly also, at some distance south of the ridge, the Lower Greensand overlaps the Wealden, and the latter, and the Kimmeridge Clay, probably rest directly upon the Palæozoics.

The outcrop of the Lower London Tertiaries is about 100 feet above the *THAMES*, whilst their depth below it varies from 200 to 300 feet, the only notch in the rim of the basin being the valley of the *THAMES* at Deptford and Greenwich, where the outcrop is 100 feet lower than the remainder of the margin of the basin, but the sectional area of the depressed portion being much less than the elevated portion, far less water can escape than can be absorbed by the sands, which are practically water-logged by the overlying impermeable clay, through which borings were carried to a depth of 80 to 140 feet at the beginning of the century, and the liberated water flowed up the boreholes, and rose permanently above the level of the *THAMES* until the supply was over-pumped, and it has fallen to 70 feet below Trinity high-water mark.

To supply the deficiency, most of the artesian wells in London have been carried down to the Chalk beneath, to intercept the water which circulates freely in the fissures and lines of joints. The level to which water will rise is steadily decreasing.

The earliest attempt in London to find Lower Greensand water was made by the *Hampstead Waterworks Company*, at their Kentish Town well, just below the first rise of Highgate Hill, and about 200 feet above the sea. This well had previously been carried to a depth of 539 feet, of which 324½ feet were Tertiaries and the remainder Chalk. A boring was commenced in 1853, and the Chalk was proved to be 645 feet thick, Upper Greensand 13½ feet, and 130 feet of Gault, with the usual phosphatic basement bed. The normal

sequence of beds was met with to this depth, 1113½ feet, then the boring passed through 188 feet of Red and Mottled Clays, Sandstones, and Conglomerates, which have been variously referred to the Lower Greensand, New Red Sandstone, and Old Red Sandstone. From the presence of fragments of *Ammonites* and *Belemnites*, Mr. Whitaker considers them probably cretaceous; but Mr. D. Sharpe and Prof. Prestwich considered these fossils to have fallen down the shaft.* When the boring reached 1302 feet, the property passed into the hands of the *New River Company*, and the work was discontinued.

These red beds are absent at Meux's Brewery, where, beneath 160 feet of Gault, occurs the well-known *Ammonites interruptus* zone, 6 inches thick; limestone, 4 feet 6 inches; Lower Greensand, 66 feet, underlaid by Mottled Red and Green Argillaceous and Micaceous shales of Devonian age, extending from 1070 to 1144 feet from the surface, or 74 feet where the boring was discontinued.

Boring at Messrs. Meux's, Tottenham Court Road:—

	Feet.
Gravel	21
London Clay	63½
Woolwich Beds	51
Thanet Sand	21
Chalk, with flints	347½
Chalk, without flints	305
Upper Greensand	28
Gault	160
Lower Greensand	67
Mottled beds, purple and green, argillaceous and micaceous shales, Devonian fossils, identified by Mr. R. Etheridge, P.G.S., F.R.S.	80
	1144

The details given by Conybeare and Phillips, 'Geology of England,' of a well in the east of London, show that, in 1821 or 1822, the water from the Chalk rose exactly to the level

* 'Guide to the Geology of London,' 3rd ed., p. 16.

of Trinity high-water mark; and this, according to Professor Prestwich, was observed in ten other wells in 1822; while in 1851 it stood 45 to 65 feet below it, or 33 to 53 feet below Ordnance Datum, and it is now pumped down to from 80 to 130 feet below datum before pumping, lowering a further 10 or 20 feet after pumping. The gradual descent of the water-level is seen in the Bank of England well, 40 feet above Ordnance Datum, and about 334 feet deep, which has been measured on the last Monday morning of 1856, 1866, and 1876, and the water-level found to be respectively 55½, 60½, 75½ feet below Ordnance Datum. As far back as 1850, the Rev. Mr. Clutterbuck showed that this depression extended as far as Hendon and Edgware on the north, and also that a sudden rise of the *Colne* affects the London wells. In 1851, Prof. Prestwich* stated the supply of individual wells varied from 10 to 300 gallons per minute; and the total yield of all of them is estimated at 10 to 12 million gallons, including the water from the Thanet Sands.

The sections passed through in several hundred wells have been collected by Mr. Whitaker, and are printed in various memoirs of the Geological Survey, especially in the Geology of the London Basin. Previous to their publication, the largest collection was that made by Mr. R. W. Mylne, F.R.S.,† who was the first to publish contour lines of equal level in the district of London. Valuable work has recently been done by Mr. J. Lucas, F.G.S., in collecting the depths to water, in the wells in the Lower Thames Valley, and drawing on maps the "artesian contours," or lines of equal level to which water will rise.

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* 'A Geological Inquiry respecting the Water-bearing Strata of the Country around London: with reference to Water Supply of the Metropolis, and including some remarks on Springs' (London: Van Voorst), 1857, in which volume there is a mine of information on the subject, up to the date on which it was published.

† 'On the Strata beneath London,' and a paper 'On the Supply of Water from Artesian Wells in the London Basin, &c.' ('Trans. Civ. Eng.,' 3rd part of vol. iii.); and the series published in 1849 by the Metropolitan Commissioners of Sewers.

Staines (Middlesex, Extra Metropolitan).—*Acres*, 1842; population, 4638. From surface wells; generally one well to each house, or one to a group of houses; rateable value, 23,717*l.*

Uxbridge.—*Acres*, 490; population, 7712. The chalk, boreholes, well and adits; upwards of 200,000 gallons, but much wasted (I.); rateable value, 28,151*l.* 16*s.* 9*d.*; the Public Health Act, 1848, and the subsequent Acts amending and extending the same.

Acton.—*Acres*, 2304; population, 17,100; the *Grand Junction Waterworks Company* (intermittent); rateable value, 45,880*l.*

Brentford.—*Acres*, 1080; population, 11,808; partly from wells, artesian and ordinary, and partly from the *Grand Junction Waterworks Company's* mains (c.); rateable value, 40,000*l.*

Chiswick.—*Acres*, 1216; population, 15,975; *Grand Junction* and *West Middlesex Water Companies;* rateable value, 58,000*l.* A constant supply of water would be preferable.

Ealing.—Population, 15,766; *Grand Junction Water Company;* about 20 gallons per head (intermittent); and surface well in gravel; rateable value, 70,000*l.*

Heston and Isleworth.—*Acres*, 6915; population, 22,717; *Grand Junction Waterworks* and private wells (constant); rateable value, 101,083*l.* Extension of mains of the *Grand Junction Waterworks Company.* It is believed the Company are applying for an Act of Parliament for that purpose.

Twickenham.—*Acres*, 2240; population, 12,479; *Grand Junction Waterworks Company*, and by private wells; rateable value, about 75,000*l.*

Harrow.—Population, 5551; well (c.); reservoir and water mains; 170,000 gallons (c.); rateable value, 29,519*l.* 15*s.* Harrow Waterworks Act, 1854. Mr. Grover, C.E., states the well struck water at 186 feet below the Ordnance Datum, and rose 101 feet above it.

Willesden.—*Acres*, 4352; population, 27,397; by the *West Middlesex Water Company;* rateable value, 98,936*l.* 15*s.*

Hampton Wick.—*Acres*, 1315; population, 2163; wells, and the *Grand Junction Water Company;* constant; rateable value, 10,850*l.*

Tributaries:—River Lea

Is 50 miles long, rises in the Chalk hills between Dunstable and Luton (348 feet) near the *OUSE* watershed, thence it traverses the Chalk to Hertford and Ware (150 feet), and, receiving the water of the *Stort*, enters the Tertiaries, flowing past Waltham, Enfield, and Tottenham. The area of the *Lea* at Lea Bridge is 570 square miles, half of which is Chalk, and the remainder Tertiary. In April, 1796, Rennie estimated the total discharge at 8880 cubic feet per minute, representing a discharge of 15·58 cubic feet per minute per square mile, and an annual rainfall of 3·53 inches. The Rivers Commission gives its average permanent flow at 45,000,000 gallons daily, at Fielde's weir, below the infall of the *Stort*. The upper district of the river above Hertford was inhabited by 80,073 people in 1871, including Luton, and the lower district, whose drainage enters the river above Hertford and Ponder's End; below Waltham, at the intake of the East London Company, by 87,802 people, including towns of Hertford, Ware, Coultham, with Bishop Stortford on the *Stort*.

Two very interesting borings have recently been made in this basin by the *New River Company*. One between Hertford and Ware has passed through the following strata, according to Mr. Hopkinson, F.G.S. Gravel, 14 feet; Chalk, 416 feet; Chalk Marl, 128 feet; Upper Greensand, 77 feet; Gault, 160 feet; or a total of 795 feet. Below this Mr. Etheridge, P.G.S., has detected traces of the Car Stone, belonging to the Lower Greensand, and 43 feet of Wenlock Shales, with bands of limestone, dipping at 40 degrees, and containing numerous fossils, including the Trilobite, *Phacops*

caudatus. The Palæozoic floor here is about 700 feet below the Ordnance Datum.

At Turnford, near Cheshunt, the ancient rocks occur at 840 feet below Ordnance Datum, and contain Devonian fossils, identified by Mr. Etheridge, P.G.S., of the same species as those occurring at Me[illegible]'s boring, as *Spirifera disjuncta* and a *Rhynchonella*.

Tributaries of the Lea:—River Stort.

This str[illegible] is 19 miles long. It also rises in the Chalk near the *OUSE* watershed, south of Royston and Saffron Walden; it reaches the Tertiaries at Bishop Stortford at 270 feet, and flows over them by Harlow (146 feet) and Sawbridgeworth.

River Maran.

This river is 11 miles long, rises in and flows over the Chalk, and falls into the *Lea* near the outfall of the *Beane*.

The *River Beane* rises in the Chalk, on the *Cam* watershed near Baldock, and falls into the *Lea* just below the base of the Tertiaries between Hertford and Ware, after flowing 11 miles.

The *River Rib* also rises near the *Cam* watershed, drains a Chalk district, and falls into the *Lea* near the outfall of the two last-described streams.

The *River Ash* drains the Chalk country above Ware, between the *Rib* and the *Stort*.

Capping many of the flat-topped hills lying between the valley of the *Lea* and the escarpment of the London Clay and Plastic Clay, overlooking the Chalk about Rickmansworth, Watford, and St. Albans, are the Pebble Gravels of probably Pre-Glacial age. It will be noticed that, with two slight exceptions of patches of gravel on the Plastic Clay, these Pebble Gravels do not occur in the country lying immediately north of the escarpment.

The Chalk is overlaid by an extensive sheet of Middle Glacial Sands and Gravels, through which narrow valleys have been cut exposing the Chalk beneath. Here and there

small outliers of Plastic Clay occur, remnants marking the former position of the escarpment further out in the Chalk plain, but the fact is very important that on the top of one of these outliers, is a patch of Pebble Gravel. This small tract is about 1 mile south of Amersham, and quite 7 miles from the Plastic Clay escarpment.

From these facts it is difficult to resist the conclusion that the Pebble Gravels were deposited on an old plain of Lower Tertiary Beds, the northward portion of which has been destroyed by the wearing back of the escarpment to its present position.

Eastward of the valley of the *Lea* the Pebble Gravels cap the heights of Epping Forest, and underlie the Boulder Clay east of Epping Station. South of Brentford, as at Hampstead Hill, these gravels rest on the Lower Bagshot Beds.

On the slopes lying above the alluvial plains of the valley of the *THAMES* and *Lea*, the Gravels do not occur; but on the south side of the valley two outliers remain at Shooters Hill and Telegraph Hill, Swancombe Park, to testify to the height and lines of the old Pre-Glacial valley of the *THAMES*. Whether the old gravels capping the low hills about Oatlands Park and Virginia Water belong to this age is somewhat doubtful, but they appear to have been deposited during the same set of conditions.

The Middle Sands and Gravels spoken of as occupying the Chalk area north of the Watford escarpment lie at the foot of it, move transgressively over it, and are found far away on the London Clay to the east, and are consequently of newer age than that of the escarpment.

On the other hand, not only do none of the Middle Sands, or the Boulder Clay, occur on the south side of the *THAMES*, but no traces of them occur on the lower valley slopes on the north side.

The most southern tract of the large mass of Boulder Clay between Brentwood and Epping is that at Havering-atte-Bower, which is about a mile and a half north of the termination of the *THAMES* Gravel of Romford, the level of the

latter gravel being about 60 feet, and of the Boulder Clay more than 300 feet. A most interesting relation of the Glacial Deposits is well shown on the Survey map, where the Middle Sands covering a large area at Black Park and Stoke Common, west of Uxbridge, extend to within a quarter of a mile of the *THAMES* Gravel of Stoke Poges and Farnham Royal, and within five miles of the *THAMES* at Windsor, and separated from the Gravels by the scarp of London Clay, which is shown in the horizontal section of the Geological Survey, Sheet 74.

From the abrupt manner in which the southern extension of the Glacial deposits is cut off, there can be little doubt that the older slope, on which they rest, has been denuded away since the time of their deposition, or, in other words, that the valley of the Lower *THAMES*, with its various sheets of terraces and alluvial gravels, is newer than these glacial deposits. From the fact of the latter being sparingly represented immediately north of the *THAMES* Valley, their thinning out southwards, and their entire absence south of the valley, one must conclude their southern limit on the Pre-Glacial plain would nearly correspond to the course of the existing River *THAMES*.

London Water Supply,* from the *Lea* Basin.—The Water Companies pumping the *THAMES* supply one half of the town and suburban population of London. The remainder, including a population exceeding 1,250,000, living in 240,000 houses, situated north of the *THAMES* and east of the Regent's Park and Charing Cross, receive their water chiefly from the *Lea*, but partly from the Chadwell Spring near Hertford, and from deep wells of the *New River Company*.

The *New River Company's* chief supply is derived from Sir Hugh Myddelton's old open conduit, constructed to contour the country from Chadwell Spring; it was 40 miles in length, 18 feet wide, 5 feet deep, with 5 inches per mile fall. Its course has been since much shortened by various

* See also pp. 179, 182, 243, and 250.

cuts, occasionally by aqueducts, one syphon and one tunnel, which, cutting across a contour, has shortened the course many miles; the necessary fall is given abruptly by a step or weir, the removal of which, if necessary, will quicken the flow of the stream, and render the channel capable of delivering a larger quantity. The flow at present is about one-third of a mile per hour, or more than 20,000,000 of gallons per day. Of the Chadwell Spring, Bunaby wrote 150 years ago :—

"Fontes lentem dantes sonum
Quæ ditarunt Middletonum."

It rises a mile below Hertford, in a circular pond 30 yards across, within a well-penned and grassed enclosure; it was yielding, when examined by the Rivers Pollution Commission, "500 cubic feet per minute of water even muddier than that of the river, which was being taken in at the floating sluice above the weir at the rate of 1700 cubic feet per minute. In summer the river water is sometimes

ERRATUM.

Page 195, line 1 from bottom, *for* and *read* but above the.

portion of which is between North and South Mimms, where the surface is chalk traversed by "swallow-holes," the dip of the Chalk is easterly, and it carries with it the water rising in the springs of Hertford and Hoddesdon.

The *New River* intercepts 15,000,000 to 20,000,000 gallons daily of the waters of the *Lea*, at a point below its junction with the *Beane* and outfall of the Hertford sewage. The basin

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of the *Lea* drains, as before stated, more than 500 square miles, of which half the area consists of chalk, in which rise the head streams that afford the larger portion of its supply (the *Stort*, the *Rib*, the *Beane*, the *Mimram*, and the *Lea*), uniting before the river enters the clay district, which, except in wet weather, adds little to the volume on its course to the *THAMES*.

The first well and pumping station is at Amwell End, near Ware, a 50 horse-power engine lifting 2,000,000 gallons daily into the *New River*, when the Chadwell Spring and River *Lea* fall below the requirements of the Company. The bore-hole is 419 feet deep, and the water rises to a few feet from the surface, forced 30 feet by pumping. Two miles further on is the Amwell Hill pumping station, where a 25 horse-power engine lifts, if necessary, 2,000,000 gallons daily; the well is 80 feet deep, with adits from the bottom, and a 40-feet boring. At Hoddesdon is a third station, with a 50 horse-power engine capable of lifting 2,300,000. At Turnford, near Broxbourne, 2,600,000 gallons can be pumped by an 80 horse-power engine. The shaft is 180 feet deep, two 18-inch borings going (in 1874) 74 feet lower. In these wells surface waters are excluded by iron cylinders carried to a sufficient depth.

At Cheshunt two storage reservoirs for fire purposes gather 39,000,000 gallons from a gathering-ground above them, with a 20 horse-power pumping engine to refill it from the *Lea* if necessary. Twenty-five miles from Chadwell Spring are 8 acres of subsidence reservoirs at Hornsey, and 2 acres of filter-beds, storing 8,500,000 gallons. About 600,000 gallons are daily pumped to the Highgate and Hampstead reservoirs. At Green Lanes, Stoke Newington, are 42 acres of subsidence ponds, 7 acres of filter-beds, delivering 4 to 5 inches per hour, delivering 10,000,000 to 15,000,000 gallons of bright, clear filtered water, which are pumped by engines of 1080 horse-power to the service reservoirs at Pentonville and Maiden Lane. The remainder of the water flows to the "*New River* Head," a reservoir of three-fourths of an acre, at Clerkenwell, with 3 filter-beds of $2\frac{1}{4}$ acres, capable of yielding 5,000,000

gallons daily, the original termination of the canal of Sir Hugh Myddelton. There are also 13 open ponds at Hampstead and Camden Park Road, for street watering, which last supply can be increased by direct pumping from the *THAMES* at Blackfriars.

The River *THAMES* frontage of the *New River* Company is about 2 miles in width, increasing northwards; supply-district 22 square miles, includes Hampstead, Kentish Town, Highgate, Hornsey, Stamford Hill, Stoke Newington, Highbury, Dalston, and the City, inhabited by 700,000 persons, living in 120,000 houses. The Company has separate mains for street watering and trade purposes, amounting to a daily average of 1,324,908 gallons; and a total storage reservoir capacity of 169,000,000 gallons, and 11½ acres of filter-beds, and covered reservoirs holding 24,000,000 gallons.

The *East London Waterworks* supplies the district lying north of the *THAMES*, and east of a line nearly due south through Tottenham High Cross, including a population of 675,000 people, in 104,637 houses (in 1874). The whole of this enormous quantity is taken from the *Lea* at Ponder's End, where a former mill conduit has become the property of the Company, and is used for the supply of the subsidence reservoirs at Walthamstow, between Lea Bridge and Ponder's End. There are eight reservoirs, holding 400,000,000 gallons, and 220 acres in extent. At Chingford Mill are other reservoirs holding half the quantity. After prolonged subsidence the water flows into a conduit to Lea Bridge, a mile further, where 19 acres of filter-beds were in use in 1874, passing through 18 inches of fine sand and 24 inches of coarse sand and gravel, from which station 20,000,000 gallons are pumped daily—three-fourths to consumers, the rest to covered reservoirs at Old Ford, where other engines deliver it to the district of the Company. The filtration is said not to be surpassed by any Company in London, not more than 1½ gallon being drawn per square foot of surface per hour, equal to a depth of 3 inches passed through during this time. The fouling of this water in 1865 was due

to a connection between the Old Ford reservoirs and the *Lea* by means of a sluice, which was used three times in that year, according to Mr. Greaves, C.E., the engineer to the Company, but it has since been entirely cut off. The hardness is reduced by filtration from 26·9 parts per 100,000 to 24·2.

The Company have power to take not more than 10,000,000 gallons daily from the *THAMES*, at Sunbury,* thence it is conveyed by 18¾ miles of cast-iron 4-feet mains, lime-washed inside and the sockets laid with Portland cement, to Finsbury Park. The total solid impurity of the water when filtered at Sunbury was 22·20, when delivered at Finsbury 22·68 parts per 100,000; hardness the same, organic impurity less.

Lea Basin Local Authorities:—

Dunstable (Beds).—*Acres*, 423; population, 4627; *Dunstable Gas and Water Company*, 25,000 to 40,000 gallons (constant); rateable value—Dunstable, about 12,000*l.*, of Upper Houghton Regis unknown, as it is not severed from the rest of the parish of Houghton Regis—Dunstable Gas and Water Act, 1871.

Luton.—*Acres*, 2600; population, 23,959; (constant); rateable value, 59,993*l.* 16*s.* 8*d.*; 28 Vict. c. 17. A well has been sunk to a depth of 475 feet, and is said to have penetrated the Chalk and reached the Upper Greensand.

Ware (Herts).—Population, 5276; well in Chalk; by reservoir; 186,000 gallons; rateable value, 19,922 2*s.* 1*d.*; Public Health Act, 1848.

Bishop Stortford.—Population, 6704; the water is pumped from a deep well in the Chalk into an adjacent reservoir; about 100,000 gallons; rateable value, 28,650*l.*; The Bishops Stortford Water Act.

Stevenage.—*Acres*, 4640; population, 3116; five public wells and about 100 private wells; rateable value, 20,000*l.*; the Sanitary Acts.

Hertford.—Population, 7585; an artesian well at the *New Waterworks* at Port Hill, and a well at the *Old Water-*

* This supply is only required when that from the *Lea* is insufficient.

works in Hartham; reservoir; 227,000 gallons; rateable value, 27,009*l.*; 5 & 6 Will. IV. c. 76, s. 94; 6 & 7 Will. IV. c. 104, s. 2; 23 Vict. c. 16, ss. 1–8.

CHESHUNT.—*Acres,* 8480; population, 7736; the supply (with a very trifling exception afforded by the *New River Company,* and also that derived from a few artesian wells), is derived from wells having surface springs as their source; rateable value, 46,959.

EDMONTON.—*Acres,* 7482; population, 23,463; a portion of the district by the *New River Company,* and the remainder by wells; a portion by artesian well of *New River Company* at Colney Hatch; another portion by various surface wells; it is in some instances constant, but it is impossible to give the quantity; rateable value, 94,000*l.*; a water supply to various places in Upper and Lower Edmonton; but it has not been decided what is necessary.

ENFIELD.—*Acres,* 12,410; population, 19,119; artesian wells, in Chalk; the water is pumped into reservoirs (two), and direct from engine; 300,000 gallons daily; rateable value, 90,362*l.*; Public Health Act, 1848.

HORNSEY.—*Acres,* 2974; population, 22,474; *New River Company,* Springhead, Clerkenwell, E.C.; rateable value, 122,703*l.*

SOUTH HORNSEY.—Population, 14,587; *New River Company;* by reservoir; daily supply; rateable value, 70,102*l.*

TOTTENHAM.—*Acres,* 4642; population, 46,441; artesian wells in the Chalk; 600,000 gallons; rateable value, 158,180*l.* 10*s.*; Public Health Acts.

WALTHAM HOLY CROSS.—*Acres,* 11,017; population, 5368; three public artesian wells, one public tank, or reservoir, fed by a spring; the houses are also generally supplied with separate springs or pumps; rateable value, 36,473*l.*

River Brent

Is 10 miles long, rises in the Tertiary hills, above Edgware, flows by Barnet, Finchley, and Hendon, and falls into the *THAMES* at Brentford.

Barnet.—*Acres*, 250; population, 4095; *Barnet Waterworks;* the Company have deep wells; 25 gallons per head (I.); rateable value, 10,400*l.*

East Barnet Valley.—*Acres*, 2593; population, 5788; artesian well, belonging to the *Barnet District Gas and Water Company;* about 25 gallons per head per day; rateable value, 33,000*l.*

River Colne

Is 26 miles long, rises in the Chalk hills, between Hatfield and St. Albans, and flows past Watford, breaches the Plastic Clay escarpment between Edgware and Beaconsfield, and traverses the Tertiaries of Uxbridge, and falls into the *THAMES* at Staines.

An experimental well was sunk in 1840, by order of the House of Lords, in Bushey Meadows, three-quarters of a mile north-east of the valley, to prove the affirmation, "that 10 inches of percolation of rainfall over the Chalk area, which is traversed by fissures from 1 to 12 feet in width, at depths of from 100 to 200 feet, which yield 408 millions of gallons of water, absorbed over the outcrop of 1200 square miles." The well had a depth of 34 feet, a diameter of 12½ feet, with boreholes of 5 inches diameter to 130 feet. The water rose to the surface 169 feet above Trinity high-water mark, and the yield was 1,800,000 gallons per day. Mr. R. Stephenson found pumping lowered the level 26 feet, which rose with a velocity of 2·02 feet a second, or 1,091,000 gallons per day. Stephenson's (or rather Paten's) scheme was to sink a well for the supply of London at Watford, and increase the supply by a tunnel in the Chalk, forcing the water into a reservoir at Brockley Hill, 146 feet above Oxford Street.

Tributaries of the Colne:—(1.) *Ver*

Rises near the Chalk escarpment, 9 miles north-west of St. Albans, flows past Redbourn, St. Albans (280 feet above the sea), and Colney Street, a distance of 12 miles, and falls into the *Colne* at Watford. Above Redbourn, Dr. Evans states, the *Ver* is absorbed by its bed. The water, however,

is obtained by five borings sunk by the late Mr. Robert Paten for the millowners, 250 feet in depth: 700,000 gallons were yielded, flowing out at a height of 290 feet above the sea.

(2.) *River Gade,*

Rising in the Chalk near Little Gaddesden, at 365 feet above Trinity high-water mark. The first mill on this stream has not a constant supply, the stream is not permanent, until the second, Bury Mill, is reached, 279 feet above the sea, and 24 miles from London. The *Gade* flows for nearly 6 miles to Two-waters, near Hemel-Hempstead, where it receives the *Bulbourne,** rising near the summit-level of the Grand Junction Canal; on the latter stream were the Chalk experimental wells. The *Gade* flows south for 7 miles, and falls into the *Colne.*

(3.) *River Chess.*

This river is 7 miles in length, drains the Chalk of Chesham and Amersham, falling into the *Colne* at Rickmansworth.

(4.) *River Misburn.*

This tributary of the *Colne* is 13 miles long, chiefly traverses Tertiary deposits, running from Beaconsfield, falling into the *Colne,* near Uxbridge.

Local Authorities in *Colne* Basin:—

St. Albans.—*Acres,* 434; population, 10,930; *St. Albans Water Company's* two deep wells; wells about 200 feet deep sunk in Chalk (not artesian); about 75,000 gallons; rateable value, 20,484*l.*

Watford (Herts).—*Acres,* 530; population, 10,073; Chalk, artesian wells; reservoir, 100,000 gallons; 300,000 gallons,

* In 1849 Mr. S. Clegg gauged the River *Bulbourne* near its source for 10 days, during which he pumped a well in the Chalk 75 feet deep, and 6½ chains north of the highest source of the river. The gauges were placed at points 528 yards, 660 yards, and 957 yards from the pumping station, and he found on the first gauge the water ceased to flow in 10 hours, on the second in 9 days, and that the volume was reduced on the third in 10 days.

intermittent; rateable value, 32,344; Health of Towns Act, 1848, and Amending Acts; new works are now being constructed, consisting of boiler, engine, and pumps, capable of lifting 600,000 gallons per hour, and a reservoir to contain 1,000,000 gallons; 12-inch pumping main, &c. At Stanmore, near Watford, a well has been bored to a depth of 396 feet in the Chalk, and Mr. R. W. Mylne states the bottom beds were dark-grey chalk marl.

Tring.—*Acres*, 3807; population, 4354; the works of the *Chiltern Hills Water Company*, and wells on occupiers' premises. The *Chiltern Hills Water Company* have mains in most parts of the town; reservoir (supply constant); rateable value, 18,906*l.*; the Chiltern Hills Spring Water Act, 1878.

Mr. S. C. Homersham has described the works of the *Chiltern Hills Spring-water Company* at Tring. They are situated on the Chalk, at an elevation of 660 feet above the sea, and supply the towns of Tring and Aylesbury, 7 miles apart, also the rural population of Aldbury, Aston Clinton, Bierton, Buckland, Cholesbury, Drayton, Beauchamp, Halton, Hartwell, Hawridge, Stone, Wendover, Weston Turville, Wigginton, &c., spread over 30,000 acres, or 47 square miles. The wells and boreholes at Tring are carried to a depth of 507 feet, the bottom of lowest borehole is 153 feet above Ordnance Datum, the level of the water between 473 and 511 feet above Ordnance Datum. The works were visited by the Rivers Pollution Commission, and were then softening 230,000 gallons a day by means of 18,400 gallons of lime water, at a cost for lime and labour of 27*s.* per million gallons. Reducing the total solid impurity from 28·60 to 8·18, and the hardness from 26·3 to 3·2 without impairing its brilliancy, transparency, and palatability; it has a normal temperature of 51° F.

Mr. Robert Stephenson,* in 1841 and 1842, described the

* Reports to the Directors of the London, Westminster, and Metropolitan Water Company.

springs, in the London and North-Western Railway cutting at Tring, as yielding upwards of 1,000,000 gallons per day, notwithstanding its high elevation.

The Lower Chalk at Tring is described by Mr. Gravatt as consisting of alternations of "hard blue clay," in a well 101 feet deep, on the line of the Grand Junction Canal. The quantity was not increased at this depth, or that found at 54 feet, which rose to the top and ran over at the rate of 1300 cubic feet per minute.

CHAPTER X.

CENTRAL, OR CRETACEOUS, THAMES BASIN.

Between Abingdon and Eton, the course of the *THAMES* is entirely over Cretaceous strata traversing the Gault, Greensand, and Chalk for 50 miles, falling from 179 feet at Abingdon to 67 at Eton.

Professor Ramsay has well shown* how the great elevation of new mountains on the flanks of the *older* Alps, at the close of the Miocene period, gave the Secondary strata, lying until then in horizontal continuity over what is now England and France, their existing low tilt or dip to the north-west, and so gave the initial north-westerly direction to the existing rivers of Northern France, the *LOIRE, SEINE, MARNE,* and *OISE;* and, by causing the Chalk of England to form a gentle slope towards the hilly country of Wales and Herefordshire, forced the *SEVERN* to run in a southerly direction, and established the first beginning of the great Chalk escarpment that has since been cut so far back by subaerial causes. But, before it was cut back any great distance, further disturbances of the strata took place to the east of it, giving the Chalk and overlying Eocene strata a decided tilt to the eastward, which caused the drainage of the Chalk area to flow away eastward. The *THAMES* then came into existence, and commenced to cut for itself a valley through the Chalk, the escarpment of which continued to gradually recede eastward, and from overhanging the valley of the *SEVERN* (which, as the Oolitic escarpment also retreated eastward) gradually widened, gaining in extent at the

* 'Quar. Jour. Geological Society.' "On the Origin of the River Courses of England."

expense of the *THAMES*, which gradually contracted its drainage area.

The gradual retreat of the Chalk escarpment at length bared the edges of the Oolitic strata, which had already obtained their south-easterly dip before the deposition of the Cretaceous strata, which, being of unequal hardness, formed another line of escarpment, which also commenced retreating eastwards, but at a far slower rate than the more readily soluble Chalk, the distance between the Oolitic escarpment of the Cotswolds and the Chalk escarpment to the east of them having gradually increased from that day to this, and the process, according to Professor Ramsay, being still in existence, so that the time must come when the Oolitic escarpment forming the present Cotswolds will have retreated so far eastward, that the larger portion of what is now the valley of the *THAMES* will, through the travelling of the watershed towards the sea, become a part of the valley of the *SEVERN*.

The Chalk, resting on the Oolites with a south-easterly dip, was at length cut down by the retreat of the escarpment to a point relatively lower than the newly-formed Oolitic escarpments to the west of it, which allowed all the water falling on the surface of the Oolites, between their escarpment to the west and the Chalk escarpment to the east, to flow down the dip of the Oolites and into the *THAMES* Valley excavated in the Chalk, which was gradually deepened as the escarpment increased in height, so that in time it was entirely breached by the river which flowed through it.

The map of the Geological Survey, with London in the centre, includes the principal portion of the valley of the *THAMES*, and the Superficial Deposit edition of the same map and of Sheet 7, and the 'Ordnance Contour Map,' published by the Royal Rivers Commission, afford the basis of the following observations:—

The chief source of the *THAMES* is about 600 feet above the sea, from it the stream descends a horizontal distance of 9 miles to the 300-feet contour, and 11 miles more to the

200-feet contour near Lechlade, from which place, to the point where the river flows through the Chalk escarpment at Wallingford, is a distance of 42 miles, to the 100-feet contour is an additional 30 miles, which is reached near Great Marlow, from which the *THAMES* descends 75 feet at London Bridge, 48 miles further on.

The top of the Chalk escarpment, near the *THAMES*, is about 100 feet lower than the source of the river, so that, supposing the valley of the *THAMES* not to have been excavated, and the river to flow along the plain at the top, the stream would have a fall of 100 feet in 62 miles, a fall very similar to that now obtaining between the 200 and 100-feet contours, which are 72 miles apart.

It has already been shown that the river, to flow over the Chalk escarpment from the lowest of its several sources, would only have a very slightly greater angle of fall than it has between the 200 and 100-feet contours, lying respectively on the landward and seaward side of the Chalk escarpment; but it is evident from the levels of the top of the *THAMES* Gravels between Windsor and Stoke Poges, where the valley is only 4 miles wide, that a considerable portion of the gorge through the escarpment has been excavated since these gravels first commenced to be deposited, and since the denudation of the southern edges of the Middle Drift. When the former channel of the *THAMES*, where it flowed through the Chalk escarpment, was only as high above its present level, as the Stoke Poges and Acton Gravels are above its present level, the river must have had 100 feet fall more than at present between the Chalk escarpment and the sea. The *THAMES* Gravel Professor Prestwich described in 1857,* as consisting of angular flints and other pebbles exhibiting a want of roundness, indicating an absence of marine action, associated pebbles of quartz and various semi-crystalline rocks, rolled into pebbles during the New Red

* 'Ground Beneath Us.' London, 1857, 'Quart. Journ. Geol. Soc.,' vol. vi. p. 201, vol. xi. p. 107, vol. xii. p. 131.

Sandstone period, and derived from the Drift, as pointed out by Dr. Buckland,* who traced the fragments in the Warwickshire Drifts to their parent source in the Bunter Conglomerates of Cannock Chase. The presence of these pebbles in the Dartford Gravel was noted as long ago as 1853 by Mr. Trimmer,† who pointed out the terrace arrangement of the ground at a height of 150 feet above the tidal level.

1233 square miles consist of impervious clay, and 3676 square miles of permeable strata, in the *THAMES* valley ‡ above Kingston, and in those of its tributaries, of which the most important, as yielding deep-seated and constant springs, are the

Bagshot Sands	211½	square miles.
Chalk	1047¾	„
Upper Greensand	126	„
Great and Inferior Oolite	327	„

The average rainfall of this area during eleven years was found to be 27·74 inches, of which only 9·25 was discharged, and no less than 17·30 evaporated, or 66 per cent.; half the discharge being due to springs, or 17 per cent., the other half to floods.

The Rev. J. C. Clutterbuck § states the incline or gradient observable in the surface of chalk water is produced by the friction or resistance that the water meets with in its passage through the interstices of the chalk which makes it take the incline; that is, the balance of the hydrostatic pressure and friction. For instance, as water is pumped from a shaft in the chalk, the water around it is depressed in the form of an inverted cone; the first foot comes down easily, but, as the pressure of the water in the shaft increases, the water will be reduced very slowly, so that unless the pump be very strong the level will not vary an inch.

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* 'Quart. Journ. Geol. Soc.,' vol. i. p. 310.

† 'On the Origin of the Soils which cover the Chalk of Kent,' part 3, 'Quart. Journ. Geol. Soc.,' vol. ix. 1853.

‡ Mr. Harrison in Report of River Commission.

§ *Op. cit.* p. 112. 1867.

Professor Prestwich, who, since the publication of his 'Inquiry into the Water-bearing Strata around London,' in 1851, has continued to add so much to our knowledge on this subject, has pointed out that the dip slope of the Chalk is not in section a straight inclined plane, but some form of variable curve, causing the water-bearing beds to dip towards the outcrop as well as in the direction of the dip, which explains the origin of the numerous powerful springs.

The discharge from springs is due to the slow percolation through the rocks, and in the case of the Chalk is probably not given off till many months after it is received. At Nettlebed, 8 miles from the *THAMES*, the head of water in the Chalk is 300 feet above the river; from it the line of saturation does not dip to the river at an average of 37 feet per mile, but gradually diminishes to 7 feet, according to Mr. Harrison, who regards the Chalk there as an inverted reservoir, from which water will continue to flow until its gravity only equals the capillary attraction of the Chalk. This condition does not arise even after 240 days' drought, during which the springs remain constant in volume, unlike those of the Oolites, which, though they have a rapid discharge in winter, not being very deep-seated, diminish largely in summer.

The line of saturation, or plane of chalk fully charged with water, slopes from the level of the outcrop of the impermeable beds supporting the water, in the direction of the dip of the strata, but not always exactly to an equal amount, the gradient being modified by the area of local supply, lithological character of the beds, intercepting influence of faults, numbers of joints and fissures, collecting and conducting the water, and other circumstances. In Herts, according to the Rev. Mr. Clutterbuck, the slope is 13 feet per mile from Dunstable to Watford.

Mr. Harrison found, in September, 1865, that the *THAMES* received from the Chalk over which it flowed no less than 80,000,000 gallons a day.

One-third of the average *THAMES* winter discharge is

derived from the Oolites above Oxford, and only one-eighth of its summer discharge, showing the rapid discharge from these porous rocks after receiving a heavy rainfall.

According to Mr. Beardmore, the chalk springs after a hot summer fall almost to a minimum in November, when there is no rain in October; but the absolute minimum is not felt until the following September, so that the storing power of the Chalk is sixteen months. The constantly diminishing springs are not replenished by the winter rain of the year before, which has not time to get down to the lower beds of the Chalk, though it feeds the land springs.

The first inch of October rain after a dry summer is lost, being taken up by vegetation; surface springs are next replenished, and, after a week's rain, begin to flow again, as the large spring at Woolmer Park.

Mr. Homersham, C.E., has had a series of drawings of bridges made, over streams draining Chalk districts, and equal areas of clay lands, which prove beyond all question the large absorbent qualities of the chalk. The drawings, which I have to thank Mr. Homersham for an opportunity of examining, show only one small arch over chalk-streams, while three or more large arches span clay-streams draining an equal area.

North and south of the Tertiary basin of the valley of the *THAMES* the Chalk hills rise to a height of from 400 feet to 800 feet above Ordnance Datum, plunging under the Tertiaries at an average elevation of from 50 feet to 200 feet. The whole of the Tertiary tract being stiff, impermeable clay, the chalk beneath is completely cut off from any possibility of percolation from above, and all water existing in the chalk must have travelled down the dip from the outcrop of the base of the Tertiaries, which extend for a distance of 90 miles in this basin, and much of the chalk area beyond this limit is covered with impermeable clay—with clay-with-flints and boulder clay, especially in Essex, Herts, Berks, Oxon, and Buckinghamshire. Probably much of the rain falling on these tracts is absorbed by

the bare chalk on the sides of the hills and exposed in the valleys, and even in districts that are bare of Drift, though the chalk is exceedingly porous, and will absorb two gallons to the cubic foot, or one-third of its bulk, and its surface cracked and fissured, it is probable that no extensive percolation of rain takes place until after long-continued rains have saturated the first few feet of chalk beneath the vegetable mould that water sinks down to low levels. The water that lodges on the surface held by capillary attraction is doubtless returned to the atmosphere by evaporation, or indirectly through the vegetation, which Professor Prestwich points out in the origin of the permanent verdure of the Chalk Downs, notwithstanding their dryness.

The *Chalk Marl* of England is generally rather compact, and of a more clayey nature than the white chalk. No water was found in it in the deep borings of Kentish Town, Harwich, Southampton, nor Calais, and in the French and Belgian Coalfields it is perfectly impermeable, keeping the water of the upper chalk from the coal-workings. But in England water-bearing fissures sometimes occur like that at Tring cutting (Stephenson), yielding 1,000,000 gallons per day.

The *Totternhoe Stone* is a rather sandy, hard, dark limestone, with occasional dark-green grain, and a few hard dark-brown nodules and fossils, forming the top of the chalk marl, about 80 feet above the Upper Greensand; it has been traced by the Geological Survey from Henton, on the eastern edge of Oxfordshire, to near Hitchin, in Hertfordshire.

It follows the windings of the various chalk coombs, and is often the water-bearing bed from which many springs at the base of the chalk escarpment rise; it weathers flaggy, and is sometimes quarried in large blocks. It is often in two or more beds split up into soft marl.

A section was laid before the Rivers Pollution Commission by Mr. John T. Harrison, embodying his observations on the water-level in the Chalk between Caversham (Reading) and Nettlebed, August, 1865. The base line is taken 100 feet above Ordnance Datum, and it commences at the River

THAMES, the top water of which is 120 feet above Ordnance Datum, from thence the ground rises to 597·8 feet above Ordnance Datum, at Nettlebed well, a little more than 8 miles distant.

Well.	To Ordnance Datum.	To Water.	Distance from Thames.	Rise per Mile.
Kidmore End	308	167	$2\frac{9}{10}$ miles	7 feet.
„ and Gallows Tree	330	187	$3\frac{3}{10}$ „	„
Higmore	460	275	$5\frac{9}{10}$ „	5 to 8 miles
Nettlebed	597·8	317	$8\frac{1}{10}$ „	Is at 37 feet per mile.

A line drawn from the top water level of the *THAMES* to the level of the water in the Nettlebed well, gives an average gradient of 20 feet per mile, or, in other words, the water should rise to a greater elevation in the area lying between the 1st and 8th mile than it does, the greatest depression being at 5 miles from which the rapid gradient recorded above commences.

Chalk absorbs the largest proportion of the rainfall of any rock, yielding it in deep wells in a condition of purity from organic matter unsurpassed by any other geological formation; and it constitutes a vast underground reservoir, in which the water is not only kept pure, but is preserved at a uniform temperature of about 10° C. (50° F.), rendering it cool in summer, and keeping it far from freezing in winter.

Every 1,000,000 gallons of water drawn from the Chalk carries with it, in solution, on an average $1\frac{1}{4}$ ton of the chalk through which it has percolated, causing an additional storage-room for 110 gallons of water; so that the yield of a well draining a given area, other things being equal, ought to gradually increase in yield, until the maximum limit of permeability is reached.

As examples of deep wells in the Chalk may be mentioned those at Dover, in the Castle, 367 feet in depth; Great Grimsby, 300 feet; Norwich Artesian well, 400 feet; Basing-

stoke, 340 feet; *Caterham Waterworks,* 490 feet. The well here has a borehole into the Greensand, the water stands in the well at 340 feet from the surface, or 369 feet above Ordnance Datum, the surface of the well being 709 feet above Ordnance Datum. Here 100,000 gallons of water are daily softened by the addition of 10,000 gallons of lime-water, at a cost of 27*s.* per 1,000,000 gallons for lime and labour, reducing the solid impurity from 27·68 to 8·80, and the hardness from 21·2 to 4·4; 700,000 gallons could be raised daily and treated if required. *Sittingbourne Waterworks,* 400 feet; Nettlebed, 378 feet; *Winchester Waterworks,* 200 feet.

The average total solid impurity dissolved in the water of these chalk wells and of a large number of others was 36·88 parts per 100,000, or 25·72 grains per imperial gallon, but consisting chiefly of bicarbonate of lime, which is innocuous to health.

Where the Chalk passes under the London Clay it becomes more compact, and consequently less permeable, but the character of the water has altered, the total solid impurity averaging 78·09 parts per 100,000, or 54·66 grains per imperial gallon, a large portion of which often consists of bicarbonate of soda.

Mr. Dugald Campbell * gives the following comparison of well water from the Chalk, and Chalk covered with clay :—

Grains per gallon.	Caterham.	Chiltern Hills.	Canterbury.	Trafalgar Square.	Combe Delafield's Brewery.	De Keyser's, Victoria Embankment.
Carbonate of Soda	..	..	..	10·58	11·60	14·67
Sulphate of Soda..	1·10	2·0	3·0	21·34	24·25	15·90
Chloride of Sodium	1·55	1·17	0·45	19·04	12·70	13·18
Carbonate of Lime	13·00	12·96	15·96	2·74	6·18	1·15

* 'Min. Proc. Inst. C.E.,' vol. xlvii. part i. p. 93. 1877.

Of wells of this class, in other districts, may be mentioned that at Witham in Essex, 600 feet in depth; that at Braintree, Essex, 430 feet; and Harrow, 408 feet. The additional impurity in the waters from the Chalk, overlaid by the London Clay, is probably derived from the Lower Tertiaries —Thanet Sands and Woolwich Beds—which occur between the chalk and the clay.*

Both in deep wells, in the Chalk, and in other formations, the water is sometimes polluted, through soakage from the superficial deposits around the shaft of the well, or through open fissures in the rock through which the well is sunk; but in all cases the result of analysis shows that the water had gained access to the well without the purification which invariably results from the passage of water through a thick stratum of porous and aerated rock. Amongst wells of this class in the Chalk may be enumerated that at Carisbrooke Castle, Isle of Wight, 240 feet in depth; Gravesend Railway Station, 70 feet; Great Bookham, Surrey, 101 feet; Harwich, 380 feet; Colchester, 400 feet; the latter being in chalk under the London Clay.

Beaconsfield (Buckinghamshire).—*Acres*, 4504; population, 1635; from wells; rateable value, 7187*l.*

Eton.—*Acres*, 137; population in 1881, 3466; *Windsor and Eton Waterworks Company;* wells in chalk (c.); rateable value, 15,119*l.*; the Windsor and Eton Waterworks Act, 1868 (private Act).

Slough.—*Acres*, 300; population, 4529; from the works of the *Slough Waterworks Company;* well in chalk (c.); rateable value, 19,772*l.*; the Slough Waterworks Company's Acts, 1868 and 1875.

Henley (Oxon).—*Acres*, 360; population, 5080; private wells to each property; rateable value, 13,486*l.*

* At the base of the London Clay there are large masses of Septaria, known by the workmen as the "water-rock." So soon as it is penetrated, the water rushes up with great violence, and fills the well. Dr. Mitchell states the pressure of the water on the under surface of the clay is so great as sometimes to *blow up* the lower 5 feet of clay in a shaft before the chalk is reached.—'Proc. Geol. Soc.,' vol. iii. p. 131.

North of the *THAMES* the elevated Chalk tract forming the Chiltern Hundreds drains partly into the Vale of Aylesbury, and partly direct into the *THAMES* between Henley and Great Marlow.

River Thame.

This stream, draining the Vale of Aylesbury, rises in the Upper Greensand north of Tring, near the *OUSE* watershed, and, passing on to the Oolitic rocks, follows their strike, flowing at the base of the Cretaceous escarpment, leaves the Kimmeridge Clay at Shotover, passes on to the Portland Oolite, Lower Greensand, and Gault, falling into the *THAMES* at 169 feet above the sea. Chief places, Stadhampton, Rycote, 194 feet, Thame, 215 feet, Aylesbury 280 feet.

Urban Sanitary Districts :—

THAME.—*Acres*, 5317; population, 3267; private wells throughout the district; rateable value, 14,539*l.*

CHIPPING WYCOMBE (Bucks).—*Acres*, 120 (parish, 5681 acres); population, 10,618; partly by wells and partly by a private Water Company; rateable value, 11,839*l.*

AYLESBURY.—*Acres*, 3328; population, 7795; rateable value, 25,401*l.* 17*s.* 6*d.*; the water used by the Local Board, who compel compulsory supply, is obtained from the *Chiltern Hills Spring Water Company* (*Limited*); supply constant; under the Chiltern Hills Spring Water Act, 1870.

River Cole.

This river is 13 miles long, rises in the Upper Greensand, flows successively over the Gault, Lower Greensand, Kimmeridge Clay, and Coralline Oolite, on to the Oxford Clay of the *THAMES* channel, opposite Lechlade, at 254 feet above the sea; on the Coralline Oolite is the village of Highworth.

Swindon Stream, 13 miles long, flows through a similar sequence of formation; one feeder rises in the Upper Greensand, the other in the Gault. The town of Swindon is

situated on the former, at an elevation of 332 feet above the sea.

New Swindon (Wilts).—*Acres,* 688; population, 17,669; supply good from the *Swindon Waterworks Company (Limited);* rateable value, 42,986*l.*

Old Swindon.—*Acres,* 1214; population, 4696; supply good from the *Swindon Waterworks Company (Limited);* rateable value, 15,543*l.*

River Oak.

This river is 12 miles long. The head waters of this stream originate in springs in the Chalk Marl above Wantage and Hendred, at elevations of 670 to 750 feet, while villages are situated on the Upper Greensand; thence its feeders flow over the Gault, Lower Greensand, Kimmeridge Clay, and Coralline Oolite, re-entering the Kimmeridge Clay before falling into the *THAMES* at Abingdon.

Wantage (281 feet above the sea), Local Sanitary Authority, comprise 2370 *acres,* with 3488 population. Water supply provided by private Company, working under Provisional Order of Board of Trade, and confirmed by Parliament, July, 1876, but private wells are still chiefly used. Rateable value, 10,979*l.*

CHAPTER XI.

BASIN OF THE UPPER THAMES, NORTH BANK.

UPPER *THAMES* and *Isis* OOLITIC BASIN.—*THAMES*, length 9 miles; *Isis*, length, 43 square miles. The whole of the Liassic district, in the *THAMES* Basin, is in this portion of its drainage area. It is drained by the head waters of the *Windrush*, the *Evenlode*, and the *Cherwell*, the latter draining the largest area, including the whole of the country around Banbury.

Mr. J. T. Harrison,* M.I.C.E., estimates the average mean annual rainfall at about 28 inches, and the area of the *Isis* and its tributaries at 783 square miles, of which 443 consist of permeable strata. He states the summer delivery of the *Isis* at Oxford to be 73,000,000 gallons a day, and the winter at 320,000,000.

With the exception of the head springs of two streams flowing from south to north, and falling into the *Isis* between Cricklade and Lechlade, the whole of the Upper *THAMES*, or *Isis*, drains country occupied by the Oolites. The river itself follows the strike of the Oxford Clay, and flows entirely in that impermeable formation, from Ewen, 4 miles from its source, to Oxford, the tract of clay averaging 7 miles in width. The tributary streams coming in from the north flow with the dip, those coming from the south against it. These streams originate in the cretaceous rocks overhanging the Vale of the White Horse. The porous Oolites, drained by the northern tributaries, are the Inferior and Great Oolites and Forest Marble. Water absorbed by them, and intercepted by faults, or rolls, in the strata north of the *THAMES* Basin, may be recovered by that stream.

* Royal Water Commission Evidence, pp. 188 and 193.

The exceedingly permeable character of the Oolites causes them to absorb a very large proportion of the rainfall, which charges the pores and fissures of these rocks with immense volumes of water, of a hardness of 20·6, but capable of being softened at a moderate cost to 5·8.

Carbonate of lime, of which the Oolitic rocks are mainly composed, is soluble in water containing carbonic acid, which causes the springs issuing from this formation to contain a large amount of solid impurity, the average being 29·69 parts per 100,000—or 20·78 grains per gallon—the average hardness being 24°, chiefly of a temporary nature.

From the exceedingly porous, absorbing, and permeable nature of the Oolitic rocks, they hold a vast store of magnificent water, which is thrown out in springs of very large volume, which, unfortunately, are rarely used by communities until it has found its way into rivers, in which it is hopelessly polluted.

The temperature of the springs ranges from 8°·1 to 11°·8 C., those of Cirencester being generally about 10°·0 C.

Shallow wells in the Oolites at Bedford; Faringdon; Frome, Somerset; Thame; Warkton, near Kettering; and Witney, Oxfordshire, yield very hard waters, with a dangerous quantity of organic matter, which, being chiefly of animal origin, causes several of them to be clear and apparently palatable.

Of *deep wells* in the Oolites, yielding unpolluted water, may be mentioned those at Scarborough, from a bore 214 feet in depth, at the Grand Hotel; from a well at Berrywood, Northampton; from the *THAMES* head well, Cirencester (60 feet deep); from a well 120 feet deep at Stowe-on-the-Wold, Gloucestershire,—all yield clear and palatable water. The solid impurity contained in solution, consisting of innocuous salts of lime and magnesia, the average amount being 23°·52 grains per gallon. The proportion of organic matter is exceedingly small, proving the Oolitic rocks are not inferior to the New Red Sandstone in the energy with which they oxidize and destroy the organic matters present in the

water percolating through them, which becomes bright, sparkling, and palatable, and perfectly wholesome.

The geology of the Oolitic districts has determined, as pointed out many years ago by Prof. Hull, F.R.S., "the sites of most of the villages. Thus along the valley of the *Evenlode* villages are planted wherever there are copious springs combined with a dry situation, circumstances generally to be found in the small lateral valleys which are excavated in the Oolites and Lias, and in these most of the villages are grouped. In other parts of the district similar advantages have determined the sites of Enstone, Kiddington, Glympton, Wootton, Woodstock, Bladon, Steeple Barton, &c. Some of these villages are perhaps as old as the Norman Conquest, and have not altered much in size through several centuries."

At Trowbridge, a well was sunk to a depth of 160 feet, and an 18-inch borehole a further 40 feet; a salt-water spring was met with in the shaft, but the water is still brackish, yielding no less than 6 lbs. of common salt from 1000 gallons of water, 3 oz. being the usual average, the hardness being 57·1 parts per 100,000.

This quantity of salt is of course exceptional; but there are no records of a good and plentiful supply of water being obtained from the Lias. In those wells which give a large yield the water is invariably derived from overlying porous gravel.

At the base of the Inferior Oolites powerful springs are thrown out, and flow in streams and rivulets over the Lias plain at their base. The Rivers Pollution Commission gives several examples of clay-land parishes of this character in the valley of the *SEVERN*, which at present do not receive their water supply until it has been hopelessly contaminated, with one marked exception, that of Coaley, near Frocester.

The common lands of this parish were enclosed under the superintendence of a Deputy Commissioner of the Enclosure Office. The frontages to the highways were fenced in, and the footpaths to the brooks closed; the several landowners who benefited by the enclosure in return laid a 2-inch

iron pipe from the spring through every hamlet in the parish, and built a small reservoir at the spring head.

That landowners should be able to charge their property as a land improvement with the cost of such proceedings as may be necessary for the provision of pure water to villages and hamlets is a matter of great importance, recommended as it is by Her Majesty's Enclosure Commission, and supported by the Rivers Pollution Commission.

The well at Witney, at Messrs. Clinch and Co.'s Brewery, is 65 feet deep. The water, which through the depth of the well has been tolerably filtered, is derived from the upper part of the Great Oolites. None of the wells of this district, however, supply water as pure as that flowing past the town in the *Windrush*. In this district a good supply of water might be obtained by carefully constructed wells of sufficient depth.

A section of the Wytham boring of 1829 was presented by the Earl of Abingdon to the Oxford Museum in 1849, and published in Phillips' 'Geology of Oxford,' p. 296. "The boring was carried to the depth of 633 feet, the strata the same as that at 596 feet," and the whole of the strata passed through were referred to the Oxford Clay; but Professor Prestwich* considers that the strata are referable to the several divisions of the Jurassic Series, as under, and compares them with the thicknesses of the Oolitic strata of the neighbourhood, estimated by Professors Phillips, Hull, and Green.

Thicknesses of Strata at Wytham boring.

	Beds.		Ft.	in.
No.	1–24	Oxford Clay	273	0
„	25	Cornbrash	10	6
„	26–32	Forest Marble	33	0
„	33–50	Great Oolite	131	6
„	51–55	Inferior Oolite	14	6
		Wanting :—		
„	56–59	Lias	170	6 (+)

* 'On the Geological Conditions affecting the Water Supply to Houses and Towns, with Special Reference to the Modes of supplying Oxford.' Oxford and London: James Parker & Co. 1876.

Thickness of Oolitic Strata at Charbury, Woodstock and Enslow Bridge.

	Feet.	ft.	in.
Cornbrash	9		
Forest Marble	25		
Great Oolite, Upper	60	179	6
„ „ Lower	70		
Inferior Oolite	15		
Upper Lias	8		
Marlstone and Lower Lias	400?		

The boring was followed by another a few years later, in the hope of obtaining water, at St. Clement's, Oxford, but unfortunately a salt spring was reached, which is still flowing. Professor Prestwich,* in a paper read before the Ashmolean Society, describes the character of the water now issuing from this artesian borehole, which was carried 420 feet through the Oxford Clay and Oolitic strata. An analysis given by Mr. Donkin, in 1876, proves this water to contain 1277 grains per gallon, a quantity not exceeded by many of the Continental saline waters. In the large proportion of *sulphates*, this water most nearly resembles some of the German mineral waters, such as Friedrichshall and Rehme, than those of England; for that of Cheltenham only contains 694 grains of saline ingredients, of which 104 grains per gallon consist of *sulphate of soda*, which at St. Clement's amounts to 357 grains.

Professor Prestwich points out that if the water in the borehole were derived from the Oolites, its solid matter would consist chiefly of carbonate of lime; if from the Marlstone, or Lias, it would be more ferruginous, and he considers the water to have its origin in the Trias.

At Bicester, an artesian boring is described by the Geological Survey as reaching a good spring at the base of the Great Oolite, 244 feet from the surface.

It is an interesting fact, pointed out by Professor Prestwich,† that three years before Sir Hugh Myddelton brought

* 'On the Mineral Water discovered in sinking the Artesian Well at St. Clement's, Oxford, and on certain Geological Inferences suggested by the Character of the Water.' ('Trans. Ashmolean Society,' June 12, 1876.)

† Water Supply of Oxford, *op. cit.*

the Hertfordshire chalk springs by the *New River* to London, one Otho Nicholson, of Christ Church, Oxford, brought the water of a small spring to Carfax Cross in that city, issuing from the base of the Coralline Oolite, on the hills above North Hincksey, a distance of two miles across the valley of the *Isis*. The spring still yields 10,000 gallons daily, but the supply was cut off and the Cross removed in 1787.

The following are some of the more important springs in the Oolite district, about Oxford, given by Messrs. Pole and Bravender in their evidence before the Royal Rivers and Pollution Commissions:—

	Gallons per Day.	Feet above Sea.	On *River*
Ablington	2,000,000	290	*Colne.*
Ampney, near Cirencester	12,000,000	340	
Bibury	10,000,000	280	*Colne.*
Bourton, Eyeford, and Donnington, near Stow-on-the-Wold	25,000,000	540 to 450	*Windrush.*
Boxwell, near Cricklade	1,200,000	280	*Churn.*
Ewen	1,000,000	310	*Isis Head.*
Seven Springs, near Northleach ..	500,000	330	*Leach.*
Seven Wells	2,000,000	690	*Churn.*
Syreford, near Cheltenham	4,000,000	590	*Colne.*

Messrs. S. F. Baker and Sons give the following details of a well at Farringdon, Berks, made in 1871. From surface to bottom of boring, 114 feet 6 inches; diameter of well, upper portion, 5½ feet; and lower portion, 4½ feet diameter; yield, about 70 gallons per minute. Strata passed through:—

	Ft.	In.
Clay, with sand and limestone	6	6
„ very sandy	4	0
Blue and grey clay and calcareous grit ..	59	0
Fine sand	23	0
Grey sand and clay, with water	22	0
	114	6

A section of the *THAMES* and *SEVERN* and Stroudwater Canal was communicated to the Royal Rivers Commission by Mr. Taunton, M.I.C.E., from which it appears that the bed of the *SEVERN* is 13·82 feet above Ordnance Datum where the Stroudwater Canal falls into it, rising to 118 feet at Walbridge, where the *THAMES* and *SEVERN* Canal commences, gradually rising for 7 miles by a series of locks, by Brimscombe and Chalford, to 358 feet at Daneway, near which it is carried by a tunnel through the watershed more than 2 miles in length. Emerging from the tunnel, the canal receives 3,000,000 gallons per day, pumped from a boring at the *THAMES* Head Springs, 11½ miles distant from Walbridge. At 15¼ miles a feeder from the River *Churn* enters the canal, and it commences its descent into the *THAMES* valley by South Corney, Cricklade, Marston, Kempsford, and Inglesham, where it joins the *THAMES* at a point 229 feet above Ordnance Datum, about 29 miles distant from Walbridge.

Abstract of Rainfall at Thames Head.

	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	Average.
Jan.	1·50	2·61	1·40	2·70	2·94	1·78	2·41	3·75	2·72	3·44	2·52
Feb.	1·54	2·02	2·74	0·46	0·55	1·60	2·17	3·41	2·05	1·39	1·79
March	2·57	2·46	2·35	4·80	1·08	3·00	1·11	1·11	2·14	2·40	2·30
April	2·61	1·52	0·76	2·47	1·13	1·06	1·09	2·20	2·55	1·93	1·73
May	1·41	3·69	1·16	3·78	1·06	1·06	1·86	0·72	2·82	1·39	1·89
June	3·37	6·13	2·22	2·70	3·54	1·42	0·97	3·21	1·33	0·40	2·53
July	1·40	1·61	3·77	1·90	0·44	0·94	4·90	2·67	3·71	0·43	2·17
Aug.	2·56	3·99	0·52	1·76	2·95	1·20	3·93	3·60	2·34	3·96	2·68
Sept.	3·05	3·08	2·73	3·39	2·96	2·81	Nil	5·81	1·43	2·95	2·82
Oct.	2·72	1·89	1·47	3·96	3·57	2·03	5·24	2·37	1·99	2·50	2·77
Nov.	2·39	2·77	4·26	0·69	2·19	2·16	3·15	1·59	0·98	1·73	2·19
Dec.	2·74	3·05	1·75	1·65	1·39	2·91	1·56	2·71	2·11	5·57	2·54
	27·86	34·82	25·13	30·26	23·80	21·97	28·39	33·15	26·17	28·09	27·93

From April to December the maximum quantity of water pumped weekly was 20,160,000 gallons, the total 769,260,000 gallons, the weekly minimum 17,280,000 (week ending

May 30th, when the canal was stopped for general purposes), and the weekly average 19,724,615 gallons. In 1864 the minimum, except when the engine stopped for repairs, was 7,560,000 gallons; throughout the whole of October and part of November the navigation was stopped for want of water. Week ending October 29th the maximum was 20,160,000, the average 15,548,000, and the total for the year 792,945,000 gallons. In 1865 the minimum was 5,040,000, maximum 20,160,000; average 19,263,000 gallons, and a total of 751,260,000 to November 11th.

The average quantity of rain that fell at Thames Head between 1859 and 1869 was 2·17 inches in October, and 2·19 inches in November. In 1867 it was only 1·99 in October, and 0·98 for November, the total for the year being 2 inches below the average. Gauging of the *THAMES* at St. John's Lock, Lechlade, by Mr. Taunton, during the dry period, gave for October a minimum daily flow of 2870 cubic feet, or 25,755,604 gallons, a maximum of 5215 cubic feet, or 46,799,826 gallons, and an average of 3242 cubic feet, or 29,092,468 gallons per diem. In the following November the minimum was 1470 cubic feet, or 13,191,892 (when the mills on the *Coln* above were not at work), a maximum of 3402 cubic feet, or 30,520,820 gallons, and an average of 2135 cubic feet, or 19,165,041 gallons.

Wheatley (Oxon.).—*Acres*, 925; population, 1020; by springs and wells; (constant) 50 gallons per head; rateable value, 3936*l.* 14*s.* 6*d.*

Oxford.—Population, 38,289; lake, formed by Great Western Railway Company excavating for gravel, and partially from River *THAMES* (filtered); 1,750,000 gallons per day of 24 hours (intermittent); rateable value, 153,259*l.*; but the charges for water in the city are not all charged according to rate; Oxford Corporation Waterworks Act, 1875; improved fittings are now being enforced for the purpose of stopping waste.

The head springs of the *THAMES* contain but a very small proportion of organic matter, which is, however, highly nitrogenized; but on reaching Lechlade they are polluted to a greater extent than the *THAMES* at Hampton Court. Irrigation improves sewage to a great extent, but does not render it a safe potable water, the effluent fluid not being free from animal organic matter, and doubtless holding germs and other noxious suspended matter. Since these analyses were made the towns above Hampton have gradually diverted their sewage of the 882,329 people that inhabited this portion of the Valley of the *THAMES* at the time of the Census of 1861.

Mr. J. Bravender, of Cirencester, has given an exhaustive account of the yield of springs in relation to the geological strata of the Upper *THAMES* Basin. Within this watershed, on the south side of the river, occur the Chalk, Upper Greensand, Gault, Lower Greensand, Portland Oolite, Kimmeridge Clay, Coral Rag, Oxford Clay; and on the north side, the Oxford Clay, Kelloway Rock, Cornbrash, Forest Marble, Great Oolite, Fuller's Earth, Inferior Oolite, and the Lias.

Of these the following are permeable, and absorb a large quantity of rain:—

Inferior Oolite.	Coralline Oolite.
Great Oolite.	Portland Rock and Sands.
Cornbrash.	Greensand.
Sandy Bed of Forest Marble.	Chalk.

A greater portion of the rain runs off the following strata as it falls:—

Lias	Except when covered with gravel.
Fuller's Earth	Nearly all runs off. Area very small.
Forest Marble ..	Quarter runs off.
Oxford Clay	Part absorbed by surface gravel, but all reaches the Thames.
Kimmeridge Clay ..	Nearly all.
Gault	Nearly all, partly reabsorbed by the Greensand.

Mr. Bravender gives the following statistics:—

	Area. sq. m.	Supply. Cubic yards per day.
Upper *THAMES:* West of *Swill* Brook and *THAMES* Head	74	174,460
North of:—The *Churn*	73	172,100
Ampney and *Marston* Brooks	32½	76,620
Coln	87	205,110
Leach	36½	86,054
Bampton and *THAMES* district ..	119	280,489
Windrush	141	332,357
Evenlode	189	445,529
South of:—The *Ray*	65½	154,426
Highworth district	9½	22,392
The *Cole*	48	113,172
	875	2,062,709

The Rivers *Churn, Coln, Windrush,* and *Evenlode* descend through valleys of denudation, the Inferior Oolite being cut through below its junction with the Lias, which throws out in springs the rainfall which has fallen on the Oolitic area above; which rainfall would have been lost to the *THAMES* had not this denudation taken place, for, following the dip planes of the strata, it would have been taken many feet under the bed of the river, both as regards the sheet of water supported by the Fuller's Earth and the Lias.

A very large proportion of the rainfall of the Great Oolite and Kelloway Rock descends through these formations to the Fuller's Earth, on which retentive clay is accumulated the enormous quantity of water found passing down the dip planes of the strata, until arrested by faults, which cause a portion of it to issue as springs.

River Cherwell

Drains, according to Mr. J. T. Harrison, 347 square miles, of which 179 consist of permeable strata. It is 40 miles in

length, rises in the Marlstone and Lower Lias country around Banbury, which town is 313 feet above the sea, and passes on to the Great Oolite at an elevation of 244 feet; it passes across this porous formation for little more than 6 miles, and again flows over an impermeable deposit, the Oxford Clay, so that this stream must yield during floods a considerable volume of water to the *THAMES*. Chief towns, Marston, Deddington, Banbury, Chipping Warden, 345 feet.

Banbury (Local Sanitary Authority) contains 3913 acres, with 12,072 inhabitants. A private Company supplies water to the Board of Health and inhabitants, averaging 250,000 gallons a day, pumped from the *Cherwell*. The rateable value is 45,413*l*. (Poor-rate Assessment).

The *River Ray* is a tributary of the *Evenlode*, falling into that river at Islip Mill; the stream flows on the strike of the Oxford Clay, and rises near the watershed separating the *THAMES* Basin from the head waters of the *OUSE*. The *Ray* is 12 miles long, and drains the country around Bicester and Ambrosden.

Bicester (Oxon).—*Acres*, 3561; population, 3306; two public wells, with pumps, and one natural spring; rateable value, 11,597*l*. 16*s*. 4*d*.

River Dorme

Is 13 miles long, rises in springs in the Inferior Oolite, flows past Woodstock, and receives the drainage of the *Evenlode*, 27 miles in length, rising at Seizincote, near Moreton, in a large spring at the junction of the Lias and Inferior Oolite. It flows over the impermeable Liassic Clays to near Stonesfield, only about 4 miles of its channel traversing the porous Inferior Oolite around Stonesfield and Woodstock. The point of junction of the two streams is 230 feet above the sea. On it are situated Blenheim Palace, Charlbury, and Chipping Norton, which contains 4167 persons. The water supply is constant,

pumped from underground reservoirs, supplied by spring at the Glyme within the district. The rateable value is 9556*l.* 15*s.* 8*d.*; the works were carried out under the Public Health Act.

Stow-on-the-Wold contains 13 *acres*, with 1636 inhabitants; water supply is from a deep well, yielding 30,000 to 40,000 gallons; supply, about 20,000 used on week-days and 10,000 to 15,000 on Sunday; rateable value, 2655*l.*; works carried out under Sewer Utilization Acts.

River Windrush

Has a length of 25 miles, rises in Inferior Oolite springs near Stow-on-the-Wold, at an elevation of from 700 to 800 feet between Bourton and Burford, chiefly flowing over impermeable clays; crossing the Great Oolite, it reaches the Oxford Clay at Witney, 275 feet, and flows across it for 8 miles before falling into the *THAMES*.

The following are the most important springs:—

Donnington	540 feet above the sea.	
Eyeford	490	„
Bourton	450	„

Witney (Urban Sanitary Authority) contains 3017 inhabitants, and has a rateable value of 6462*l.*

A boring of great interest has recently been made at Burford, west of Oxford, which has, after passing through the Oolites and 598 feet of Lias, 10 feet of Rhætic, 291 feet of Red Marls, and 137 feet of Red Sandstone, Conglomerate, and Marl, passed into true Coal Measures, which continued to the depth in which the boring was obliged to be discontinued owing to the small size of the borehole. In the Carboniferous Beds occurred true Coal Measure plants, determined by Mr. Etheridge, P.G.S., F.R.S., and a coal-seam of some thickness.

Professor Hull, F.R.S., has described, from time to time, the marked south-easterly attenuation of the Triassic and

other Lower Secondary strata. The following measurements are partly quoted from him:—

Formation.		Lancashire. Worcester-shire.	Stafford-shire.	Leicester. Warwick.
		Feet.	Feet.	Feet.
Keuper Series	Red Marl	1500	800	700
	Lower Keuper Sandstone ..	450	200	150
Bunter Series	Upper Mottled Sandstone	500	150	Absent.
	Pebble Beds	500–1000	100–300	0–100
	Lower Mottled Sandstone	200–500	0–100	Absent.

The distance from the Liverpool district to that of Warwick is about 100 miles, so that the beds have thinned at the following rate per mile:—

	Feet per Mile.	
Red Marls	8	
Lower Keuper Sandstone	3	13
Upper Mottled Sandstone	5	
Pebble Beds	7	11
Lower Mottled Sandstone	5	

Comparing these results with the attenuation observable between Staffordshire and Warwick, half the distance, the gradient is seen to be very much less:—

	Feet per Mile.
Red Marls	2
Lower Keuper	1
Bunter Beds	9

With these results, the estimated thickness of the Burford Beds, 40 miles south of Warwick, should be:—

	Calculated.		Actual Thickness.
Red Marls	620	710	428
Lower Keuper Sandstone ..	90		
Bunter Series	nil.		

Proving that the beds have thinned 8 feet per mile southwards, more than the amount between Staffordshire and

Warwickshire, and that the attenuation goes on from the bottom upwards; which result is of some value in endeavouring to ascertain to what extent the Cretaceous rocks and Oolitic rocks of the South of England may be underlaid by the Trias, and especially the water-bearing portion of it.

The new Crossness boring has, after passing through the Gault with its characteristic basement phosphate bed, reached a Marl, with coarse partings containing pebbles, which is considered by Messrs. Etheridge, Whitaker, and myself to be probably referable to the Trias, and it is a matter of considerable scientific interest to ascertain its thickness, and the nature of the underlying rock.

If a line be drawn at right angles to the direction of the line of attenuation of the Trias, through Crossness westwards, it will pass through Reading and Marlborough, from which line Burford is only 25 miles distant, which would give for the Red Beds an estimated thickness of 178 feet along this west-south-west line of strike.

River Leach, 17 (?) miles long, rises at the Seven Springs, Northleach, on the Great Oolite, 553 feet above the sea, and falls into the *Isis* below the infall of the *Cole* at Lechlade.

River Colne.

The *Colne* is 21½ (?) miles long. It rises at Syreford Spring, 599 feet above the sea, at the top of the Lias, and flows through a similar sequence to the *Churn*. It is fed by Winson Spring, at 300 feet, Ablington Spring, at 290 feet, Bibury Spring, at 280 feet, on the Great Oolite, and reaches the Oxford Clay at Fairford, 296 feet above the sea; it falls into the *Isis* above Lechlade.

In addition to this, 3,000,000 gallons of water are pumped up from the Fuller's Earth by the engine at the Thames Head well, for the supply of the Thames and Severn Canal. The whole of this water would otherwise flow down the dip planes of the strata, and be lost to the *THAMES* Valley.

The principal loss to the basin of the *THAMES* is in the area occupied by the Inferior Oolite—about 106 square miles in extent. Much water is lost in the *Colne* Basin, and the River *Arun*, in 3 miles run over porous Inferior Oolite, sustained a loss of 100,000 gallons per day.

The late Professor Phillips suggested the making of embankments across some of the porous beds of the Oolitic tributaries of the *THAMES* above Oxford. It was objected that, were the water thus forced back up the dip planes of the strata, it would flow into the deeper valleys of the tributaries of the *SEVERN*, on the other side of the *surface watershed.*

River Churn.

This stream is 18½ (?) miles long. It rises at the Seven Wells, in the Inferior Oolite of Cotswold, at 694 feet above the sea, and flows in the direction of the dip, but with a gradual inclination, so as to cause it to pass successively higher beds, the Fuller's Earth, the Great Oolite, and the Forest Marble, passing Cirencester at 368 feet above the sea; it reaches the Oxford Clay, and falls into the *Isis* near Cricklade, at an elevation of 268 feet above the sea. Boxwell Spring, near South Cerney, issues from the Great Oolite, at 280 feet above the sea. Seven miles from its source the *Churn* was found by the late Mr. Simpson, Past-President Inst. C.E., to have a volume of 320 cubic feet per minute, gradually diminishing to 45 cubic feet by absorption of water by the porous strata. This water, Mr. Taunton has since shown, is returned to the *THAMES* Basin by springs thrown up by faults.

Cirencester (Local Sanitary Authority) contains 2500 *acres*, and 7703 inhabitants. It is supplied by private wells, which yield water of pure quality from a gravel bed, in which the level of the water varies as much as 8 feet. Mr. Taunton has shown that this water is absorbed by Oolitic strata, higher up the stream.

Thames Basin North of the Estuary.

Population in Census of 1871.

Counties.	Population.	Density.	Proportion of Population probably living in the Group.	Population about
E. Norfolk	438,511	3·0	$\frac{1}{2}$	219,255
Suffolk	348,479	2·8	$\frac{3}{4}$	261,360
Essex	466,427	2·2	$\frac{99}{100}$	461,763
Herts	192,725	2·2	prac. all.	190,000
Middlesex	2,538,882	0·07	All.	2,538,882
Buckingham	175,870	3·0	$\frac{2}{3}$	117,247
Oxford	177,956	2·6	All.	177,956
Gloucester	534,320	1·5	$\frac{1}{4}$	133,580

Population in Census of 1881.

E. Norfolk	444,825	3·0	$\frac{1}{2}$	222,412
Suffolk	356,863	2·6	$\frac{3}{4}$	267,648
Essex	575,930	1·5	$\frac{99}{100}$	570,171
Herts	202,990	1·9	prac. all.	200,000
Middlesex	2,918,814	0·7	All.	2,918,814
Buckingham	176,277	2·0	$\frac{2}{3}$	117,518
Oxford	179,650	2·6	All.	179,650
Gloucester	572,480	1·4	$\frac{1}{4}$	143,120

CHAPTER XII.

SOUTHERN TRIBUTARIES OF THE THAMES ABOVE ABINGDON.

CENTRAL OR CRETACEOUS *THAMES* BASIN (*South Bank*).

THE absorption in the Chalk area lying between the Vale of Pewsey and the gorge of the *THAMES* between Wallingford and Reading is considerable, and it is traversed by no stream of importance discharging into the *THAMES* within the Cretaceous area. On the northern escarpment streams rising in springs flow north and discharge in the Oolitic area, while the *Kennet* draining the southern margin flows across the Tertiaries.

Professor Ansted* observes that "the bottom beds of the Chalk are usually of lower specific gravity than the upper," and regards the upper chalk as the conductor, and the lower chalk as the containing portion.

The Chalk Marl on the tract between London and Hants Basin forms a rich soil, suitable to the growth of hops, wheat, and clover at Selborne. It was described by the Rev. Gilbert White as decomposing into white "malm" or natural "marum."

Mr. Bristow describes the Chalk between Basingstoke and Micheldever, and near Andover, as "dry, bare, and open country, comparatively free from the growth of timber in consequence of the absence of drift, which produces a 'more luxuriant and picturesque appearance.'"

WALLINGFORD. — *Acres*, 380; population, 2803; from private wells; 3 public wells (constant); rateable value, 8751*l.* 11*s.* 4*d.*

* 'Proc. Inst. Civil Engineers,' vol. ix. p. 361.

READING.—*Acres*, 2094; population, 42,050; the River *Kennet;* pumped by water power into reservoir and filtered; 1,100,000 gallons (constant); rateable value, 138,460*l.*; the Reading Waterworks Act, 1851; the Reading Waterworks Act, 1868; the Reading Local Board Waterworks Act, 1868; the Reading Local Board Waterworks, Sewerage, Drainage, and Improvement Act, 1870.

River Kennet,

Rising on Marlborough Downs at the top of the escarpment overlooking Calne in the Lower *AVON* Valley, flows 45 miles past Marlborough (420 feet) and Hungerford over the Chalk, reaching the Tertiaries at Newbury, and passing across them, and falls into the *THAMES* at Reading.

The Urban Sanitary Authority of ABINGDON is about to commence a scheme for the supply of the town with water. At present its supply is from private wells; its district includes 345 *acres*, with 5799 inhabitants, and a rateable value of 15,960*l.*

MARLBOROUGH (Wilts).—*Acres*, 196; population, 3343; private wells in Chalk give good supply; rateable value, 9887*l.*

NEWBURY (Berkshire).—Population, 5662; wells; waterworks just completed by a Company; rateable value, 20,537*l.*

SPEENHAMLAND.—*Acres*, 112; population, 1101 in 1871; wells; district within supply of *Newbury District Water Supply* (*Limited*), who pump their water from a well on low ground to a reservoir on ground capable of supplying highest point, constituted under an Order of Board of Trade, confirmed by Act 39 & 40 Vict. c. 92; rateable value, 4289*l.* 13*s.* 7*d.*

Mr. T. Hennell, C.E., proposed to abstract the water used by the Basingstoke Canal for the additional supply of London, calculating 12,000,000 gallons could be obtained from the first 8 miles at the Basingstoke end, which passes through Chalk, and about 2,000,000 gallons from the district of the Bagshot Sands, between Farnborough and Woking.

He proposed to utilize the canal as a conduit. The present run of the canal from springs and two or three small streams is 3,000,000 gallons a day. The chalk water proposed to be added to the supply was to have been one-third of the volume of each of the tributaries of the *Loddon*. In the Bagshot district, he relied on Mr. Bateman's figures in his report in 1852, who gives a drainage area of 20 to 30 square miles, and considered 7,000,000 gallons additional could be here obtained, making 21,000,000 gallons in all.

The head springs of the canal, yielding 2,500,000 gallons a day, were stated to be at Greywell, about 6 miles from Basingstoke, the summit-level reaching from Basingstoke to Aldershot, at an elevation of 252 feet above Ordnance Datum. The canal ends at the River *Wey*, near Weybridge; and a conduit was to have been constructed to the *London Water Companies'* reservoirs, 8 miles distant, at Thames Ditton.

In addition to the 2,500,000 gallons from the Greywell springs, the canal intercepts the River *Whitewater*, rising half a mile from Greywell, discharging 10,500,000 gallons a day in October, 1866, and 14,500,000 gallons a day in March, 1867. The Maplederwell springs run 1,980,000 gallons per day, and the Newram springs 4,500,000 gallons. The latter are within a mile of Basingstoke.

The *London Clay* increases in thickness eastwards from 50 feet south of Newbury, 15 feet at Great Bedwin, to 470 to 480 feet in the Isle of Sheppey and the opposite coast of Essex.*

The clay is largely dug for puddling purposes, and when burnt forms a good cover to railway cuttings of loose and porous material.

Mr. Bristow, F.R.S.,† in endeavouring to explain the reason of the blackness of the basement bed pebbles, suggests that, as newly fractured black chalk flints become paler after exposure to light, heat, and moisture, as seen in old houses

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* Prestwich, 'Q. J. G. S.,' vol. x. p. 407.

† 'Memoirs of the Geological Survey. Explanation of Sheet 12.'

and walls, and grey cornelian, after two years' exposure to the sun, and to subsequent artificial heat, becomes red, so, too, red-coloured flints in the drift may have lost their blackness through long exposure, whilst those in the basement bed have retained theirs through being covered up quickly.

Professor Prestwich, who first made out the detailed structure of the *Bagshot Beds*, wrote of them in 1847: "Forming usually barren sandy districts, and rising over great part of their area into ranges of heath-covered hills, the Bagshot Sands have remained comparatively unexplored since Mr. Warburton described them" (in 1821). The Lower Bagshots consist of about 150 feet of white and light-yellow fine sands, with occasional thin mottled clay at the top, as at Woking. Their junction with the underlying London Clay is always marked by a line of soft rushy ground, due to the percolation of water from the permeable sands.

Subsequently these beds were investigated by the Geological Survey, especially by Messrs. Bristow and Whitaker. At Newbury Union, Mr. Bristow describes * "a bed of white pipe-clay, containing the leaves of plants, at a depth of 30 feet from the surface, which bed corresponds precisely with the pipe-clay deposits of the Isle of Purbeck, which are so rich in vegetable remains, and which there, as well as at Bournemouth and in the Isle of Wight, form a part of the Lower Bagshot Beds."

At Ramsdell occurs a thick strong clay, much resembling at first sight London Clay, but in reality being an "imperfect pipe-clay, intermediate in quality between the true Bagshot pipe-clays and the more sandy bed of ordinary London Clay." † Beneath this Ramsdell Clay occurs a bed of loam, in which is a plentiful supply of water. Tiles and bricks are made from the clay. Bricks are also made from clays of this age, at Rayleigh, in Essex, some of the beds being used for tiles and pipes.‡

* 'Mem. Geological Survey,' vol. iv. p. 312.
† *Op. cit.*, 313.
‡ *Op. cit.*, 328.

The precise horizon from which the Greywether Sandstone boulders scattered throughout the South of England is doubtful, but it is probable that they are of Bagshot age. Dressed, they form an almost indestructible building stone of pale grey colour, as is well seen at Windsor Castle, which is mainly built of it.

River Lamborne, a tributary of the *Kennet*, is 16 miles long; flows from north-west to south-east, and falls into the latter; drains the Chalk country around Lambourne, Shaw, and Boxford.

Lower Thames or Tertiary Basin (*South Bank*)

Extends from the outfall of the *Kennet* at Reading to the watershed, and separates the drainage areas of the *Wandle* and the *Mole* from those of the *Darent* and the *MEDWAY*, at which the Ordnance Survey places the somewhat artificial boundary between the areas drained by streams falling into the *THAMES* from those falling into its more purely tidal waters.

River Emborne.

This river runs south of, and nearly parallel with, the *Kennet*, drains a Tertiary district, and falls into the latter river at Ufton, at an elevation of 169 feet above the sea. In its drainage area are Emborne, Newton, and (King's Close).

River Loddon

Is 15 miles long, rises in the Chalk hills of Basingstoke and Odiham, near the watershed of the Hampshire Basin, and drains the Tertiary district lying between Newbury and Wokingham. The Bagshot Sands have overlaid the impermeable London and Plastic Clays. Mr. Lucas* estimates the Chalk at 83 square miles, and the underground contributing Chalk area at 96½.

At Basingstoke 6681 persons live in the district of the Urban Sanitary Authority, which has a rateable value of

* 'Min. Proc. Inst. Civil Engineers,' "The Chalk Water System," 1877.

27,801*l.* 5*s.*, and is supplied with water by a private Company pumping from the Chalk, 85,000 gallons being taken by railways, and 80,000 by the town.

Hurst, Shinfield, and Monks Sherborne are in this watershed.

River Blackwater.

This river is a tributary of the *Loddon;* it is 10 miles long, drains the Bagshot Tertiary district near Aldershot, passing under the Basingstoke Canal 260 feet, and falls into the *Loddon.* Sandhurst is in this basin.

Wokingham.—814 acres, with 3100 inhabitants; is of a rateable value of 10,000*l.* Supplied with water by private wells, but a Company is forming.

Between the infall of the *Loddon* and the *Wey*, is the district between Wargrave, Cookham, Maidenhead, Windsor, Egham, and Chertsey. The London Clay and Lower Tertiaries have been bored into to a depth of 600 feet at Sandgate, near Chertsey, without finding water.

Maidenhead.—*Acres*, 2560; population, 8219; partly from ordinary wells, and partly from the *Waterworks Company;* rateable value, 34,492*l.*

New Windsor.—*Acres*, 2730; population, 12,273; from the works of the proprietor of the *Windsor and Eton Waterworks;* wells sunk in the Chalk; water raised by water or steam power; 38 gallons, of which 18 are wasted (intermittent); rateable value, 57,380*l.* 10*s.* The Windsor and Eton Waterworks Acts, 1868.

River Wey

Is 38 miles in length; rises in the Chalk and Greensand of Selborne, near Alton, within the Weald area; thence it follows the strike of the Greensand and Gault to Farnham, where it enters the Lower Greensand, and flows to Godalming, where it turns abruptly northwards, breaches the Chalk escarpment at Guildford, traverses the Tertiary plain north of the Hog's Back, and passes by Woking to the *THAMES*

at Chertsey. Mr. Lucas estimates the Chalk area at 58 square miles, of which about 40 are in Hants.

Alton, with 4510 inhabitants, is supplied by an artesian well 130 feet in the Chalk, at Windmill Hill, pumped into a reservoir holding 80,000 gallons, constructed under the Public Health Act, 1875. The daily consumption is 25,000 gallons, the supply constant; rateable value, 15,538*l.*

Godalming.—*Acres*, 90; population, 2505; wells.

Guildford.—*Acres*, 531; population, 10,858; well in Millmead, Guildford; by reservoirs, into which the water is pumped for distribution by gravitation; 200,000 gallons (13 hours); rateable value, 40,590*l.*; the Public Health Act.

Aldershot.—*Acres*, 4177; population, 20,140; land springs; storage is made underground by means of culverts, with open joints in the brickwork, the whole of which are connected to wells, from which water is pumped into reservoirs of sufficient altitude to supply the town at constant pressure; artesian well bored, but not connected; from 50,000 to 60,000 gallons (constant); half population use pump water; rateable value, 25,500*l.*

Farnham.—Population, 4530 in 1881; from a private Company's works, well, and the river; the Authority has no works of its own, nor has it any contract for supply; the supply is by private arrangement between the Company and each of its customers; not constant; rateable value, 13,125*l.*

Professor Prestwich states the Bourne Mill, near Farnham, is turned by a fine spring from the Chalk.

Mr. Topley,* commenting on the effect of the Wealden flexures, states that "an anticlinal line probably cuts off the supply, when valleys along this line reach down to the retentive bed. It certainly does when the valley runs along the strike of the anticlinal; but to a very large extent it does so when the valleys *cross* the anticlinal. Whether or

* 'Memoirs of the Geological Survey of England and Wales. The Geology of the Weald.' By W. Topley. London, 1875.

not the supply is cut off when the retentive bed is not reached by small valleys along the anticlinal will depend upon the height of the water-level at the escarpment and major valleys, and the distance of each from the place in question."

Any flexure that steepens the dip narrows the outcrop, and limits the collecting area; the springs of Haslemere, and others south of the Hindhead anticlinal, Mr. Topley thinks possibly drain south. Some waters draining underground to the west under Woolmer Forest may, he thinks, work their way to the *THAMES*, but the greater part goes to the Hampshire Basin.

The Rivers Pollution Commission gives analyses of waters from the Lower Greensand at Farnham; of a spring in Mother Ludlam's Cave at Moor Park; of a spring at Hindhead; from a spring on the north side of Gibbet Hill; from a spring in the railway tunnel at Sevenoaks; from a spring at the Vicarage, at Witley Park, Surrey; from an overflowing well at Redhill railway station: an average of these 5 gives a temperature of 10·1 C., a total solid impurity of 18·25, of chlorine, 2·45, of hardness, 10·5, of which 3·6 was permanent. "The water is of excellent quality, uniformly colourless, clear, sparkling, and perfectly wholesome."

In the Hindhead, Leith Hill, and Black Down district, Mr. Topley calculates the daily yield of the Lower Greensand at 27,000,000 gallons * of water under 1° of hardness, becoming harder as it flows. The springs of this area, except those flowing from the Devil's Punch Bowl, are not

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* From Mr. Napier's gaugings, Mr. Topley calculates :—

From 15 springs and rivulets in Hindhead and Blackdown					20,988,738
„	4	„	„	Hascombe Hills	2,049,808
„	3	„	„	Leith Hill	4,127,154
					27,165,700

Subsequent observers found the water harder, Mr. Bateman stating that 33,000,000 gallons issued from the Lower Greensands, with 12½ degrees of hardness.

due to anticlinal rolls, but probably to the valleys reaching the line of saturation.

The plentiful supplies derived from this formation have been suggested as suitable for the requirements of London, but unfortunately it appears to narrow its area around the ancient Palæozoic ridge underlying the metropolitan area, though 450 feet in thickness in Reigate, and 200 feet in Bedfordshire. The boring at Meux's Brewery has established its occurrence for the first time in the London district, but it is of an exceedingly compact nature.

East Moulsey.—Population, 3290; private wells and the *Lambeth Water Company;* rateable value, 17,818*l.* 10*s.*; the Lambeth Waterworks Act, 1871.

Ham Common.—*Acres*, 150; population, 1349; partly from wells and partly from a Water Company; rateable value, 4048*l.*

River Mole

Is 35 miles long, rises within the Weald escarpment, north of the watershed at Horsham, at an elevation of 225 feet, and flows through the gorge in the Chalk Downs immediately north of Dorking. Leaving the Chalk at Leatherhead, it traverses the Tertiary and the *THAMES* Gravel by Esher, and falls into that river above Kingston.

Mr. Lucas estimates the Chalk in this basin at 23 square miles, and considers the underground drainage of 5½ square miles flows into other basins, under the Tertiary strata.

At Cobham, a boring penetrated the London Clay, and was carried to a depth of 412 feet into the Lower Tertiaries, but they consisted of Mottled Clays, and were not water-bearing.

Reigate.—*Acres*, 6006; population, 18,656; the old town of Reigate and its environs are chiefly supplied by the *Reigate Water Company*, which draws its water from a well sunk in the Lower Greensand formation. Redhill and the eastern part of the borough chiefly by the *Caterham Spring Water Company*, which draws its supply from a deep well sunk through the Chalk formation at Caterham, where it is

softened by Clark's process. But both at Reigate and Redhill many houses are still supplied by shallow wells on private premises. The *Reigate Water Company* and the *Caterham Spring Water Company* have reservoirs in connection with their respective works, and the latter Company is enlarging its works; (constant); rateable value, 91,307*l.* 7*s.* 7*d.* The Caterham Spring Water Company's Act is 25 & 26 Vict. c. 83. The *Reigate Water Company* is incorporated under the Limited Liability Companies' Acts.

Professor Prestwich states that a well was sunk at Gatton Park, through 330 feet of "firestone" and Gault, and 25 feet of red clay and pebbles. The water rose to within 290 feet of the surface.

Dr. Fitton describes a well at the Feathers Inn, Merstham, 150 feet, through Gault and Lower Greensand, with a plentiful supply of water.

Professor Prestwich states that at Wood Farm, three miles north of Merstham, the Chalk was traversed to a depth of 400 feet, and the Chalk Marl reached.

In 1850 the Hon. W. Napier proposed to collect the rainfall of the Greensand area as surface water, which he estimated at 40,000,000 gallons daily, and convey it by aqueducts to London, but 20 years later the danger of surface pollution was recognized. This plan was not in favour, and there was a decided preference for the scheme of supplying London from the underground store of water, supposed to be contained in the Lower Greensand. The Royal Commissioners on Water Supply laid great stress upon this in their report, stating:*

"It is known that the Lower Greensands exist at Reigate, and are about 450 feet thick, and that they occur again in Bedfordshire with a thickness of about 200 feet. In both cases they dip towards London, disappearing beneath the Gault. We know that they do not exist under London (Kentish Town). It follows, therefore, that in the one case

* 'Report of Royal Commission on Water Supply,' 1869, p. 87.

they cease at some point between Reigate or Merstham and London, and in the other between Baldock and London. As at both ends they are of considerable thickness, and the Gault is continuous, it is certain that the Greensands must range from these outcrops some way towards London, probably thinning off gradually against the flanks of the underground ridge of old rocks. So far as they continue, so far will they form a valuable and copious water-bearing bed, the water from which would overflow at the levels lower than that of their outcrop. The extent of their underground range could only be determined by boring. It might be as far as Croydon, or even still nearer to London. The same would happen to the north of London, but the distance there is greater, the beds are not so thick, and the conditions generally are less favourable. The great purity of the water from the Grenelle* and other artesian wells in the Lower Greensand is well known, and there is reason to suppose that the quality of water obtained from the same formation in the vicinity of London would prove equally good. The excessive length of filtration would at all events ensure freedom from organic impurities."

"The quality of the water flowing from the Lower Greensands is excellent for all domestic purposes, being bright and limpid, of a degree of hardness varying from about 3° to

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* Mr. W. W. Smyth ('Reports on the Paris Universal Exhibition,' 1867, vol. iv.) quoting M. Cassagnes (Portefeuille Économique des Machines, Dec., 1866), states that the height of the surface above the level of the sea of the artesian wells near Paris, drawing water from the Greensand, is as follows:—

Grenelle, 121·3 feet English, with a depth of 1800·7 feet.
Passy, 305·2 feet, depth of borehole 1923·7 feet.

The diameter of the Passy borehole being 1 metre, or 3·28 English, with an internal diameter of tube of 2·4; that of Grenelle being 9 inches to 6 inches at the bottom.

New wells have been sunk by Messrs. Degousée and Laurent, at Chapelle, on the extreme north of Paris. Also by Messrs. Dru (formerly Mulot and Dru), at the Butte aux Cailles, with diameters of 4 or 5 feet. The work done at Messrs. Dru's borehole, was 94 centimetres in a working day, in chalk and flint, with a boring tool weighing 2 tons 18 cwt., attached to wooden rods with iron connections, each rod being 10 metres in length.

9° of Clark's test, and generally very free from organic matter." *

The experience gained by boring since the Report was published is not favourable to this scheme, for the Lower Greensand discovered at Turnford and at Meux's Brewery is so compact as to render it improbable that it obtains any underground supply from its northern outcrop, indeed, in some borings it is entirely absent, as at Crossness. As regards the amount to be derived from the southern outcrop of the Lower Greensand, it will be remembered that the crop of the impermeable Gault is always above that of the Lower Greensand on a hill-slope, so that a portion of the rain falling on the Gault will be absorbed by the sand as well as the rain falling on its own area. The amount absorbed is necessarily limited by the capacity of the sands for absorption, varying in amount in different beds. When the wettest weather plane of saturation is reached the level rises somewhat above that of the river running through the lowest ground, the rock lying between this plane and that of permanent saturation can only absorb the amount of rainfall that its springs can deliver, the interstices of the grains of sand beneath being already charged with water, and they can receive no more. In this case excessive rainfalls do not add to the underground volume, but pass off in floods, fully charged permeable rocks neccessarily acting as impermeable material.

London Water Supply—from South Bank of THAMES.

Lambeth Waterworks.—A section of the River *THAMES*, given by Mr. J. Simpson, C.E., to the Rivers Commission,† taken opposite the Crown and Anchor public-house, and immediately above the *Lambeth Waterworks Company's* filters at Ditton, show a width of the river at its summer level of from 181 feet to 197 feet, and a sectional area of 1153·3

* 'Memoirs of the Geological Survey. Geology of the Weald,' p. 359.

† 'Royal Commission on Water Supply,' 1869, p. 89, Minutes of Evidence.

square feet to 1195·1 square feet taken in 1852, and a hydraulic mean depth of about 6 feet. The mean surface velocity at the summer water-level was 1·25 foot per second, at 7″ below (taken July, 1858) was ·75 foot per second, at 6″ below (taken July, 1864) was ·80 foot per second. The Lambeth pumping station is on the south bank of the *THAMES*, at Thames Ditton, between the Rivers *Mole* and *Hog's Mill*, thence their main runs east-north-east, by Merton, Upper Tooting, and Balham Hill, to reservoirs at Brixton and Norwood, their district of supply extending from the *Mole* to the *Ravensbourne*, and bounded to the north by a zigzag line from Teddington to Clapham.

Chelsea Waterworks. — Pumping station south of the *THAMES*, at Thames Ditton, by those of the Lambeth Company; the main runs, by Kingston and Putney, to Fulham, with reservoir on Putney Heath. The supply area has a frontage on the *THAMES* from a mile north of Fulham to Westminster Bridge, and includes Fulham, Chelsea, Pimlico, and Hyde Park.

Hog's Mill River.

Feeders rise on the slopes of Epsom Downs, a little below the 150 feet contour, descend to the 100 feet contour, near Ewell Station, to the 50 feet, about half a mile north of Malden, and fall into the *THAMES* at Kingston.

Epsom (Surrey, Extra Met.).—*Acres*, 4390; population, 6276; wells bored in Chalk; water stored in reservoir; supply, 180,000 gallons, between 7 A.M. and 7 P.M.; rateable value, 31,067*l.*; Public Health Acts. A private well at Avenue House penetrates the Tertiary to a depth of 172 feet, the surface is about 96 feet above Ordnance Datum, and the water line 65 feet above that level.

Kingston-on-Thames.—*Acres*, 1085; population, 19,875; *Lambeth Waterworks Company*, who derive their supply from the River *THAMES;* rateable value, 80,174*l.*

New Malden.—Population, 2535; *Lambeth Waterworks Company* (*River THAMES*); rateable value, 17,596*l.*

Surbiton. — *Acres,* 1000; population, 9416; River *THAMES. Lambeth Waterworks Company,* and wells; rateable value, 72,521*l.*

Teddington.—*Acres,* 1120; population, 6599; from the River *THAMES* and wells; Southwark Water Company's Act; rateable value, 32,000*l.*

The valleys of this basin have been cut sufficiently deep to reach the permanent water-bearing stratum, and form an "area of overflow," in which the rainfall absorbed by areas at higher elevations is yielded in springs, which feed numerous streams. In artesian wells sunk in such tracts the water rises to the top of the boring, and often much above it, as at Kingston (Hodgson's Brewery) the water rose 6 feet above the surface, or 31 feet above Ordnance Datum. The large numbers of wells that have been sunk in the Metropolitan district during the last fifty years have caused a permanent depression, and, the demand being greater than the supply, large numbers of springs have ceased to run and wells to overflow, and the volume of those still running has much diminished. In consequence of the steady fall, the engines of the *Croydon Waterworks* have had to be lowered 20 feet.

Richmond.—*Acres,* 1208; population, 19,068; at present a temporary well, made by the Urban Authority, after the supply to the town, formerly given by the *Southwark and Vauxhall Water Company,* without Parliamentary authority, was cut off by that Company on the 14th January, 1877, 475,016 gallons; intermittent; artesian well, in progress, has now reached the Chalk; reservoir, in Richmond Park, holding 750,000 gallons; rateable value, 117,921*l.* for 1877–78; but 122,046*l.* for 1878–79; Public Health Act, 1875, section 51, *et seq.*

Beverley River.

This stream rises on the northern slopes of Banstead Downs, just below the villages of Cheam and Sutton, between the 100 feet and 150 feet contours, drains Wor-

cester Park, Morden, Richmond Park, and Roehampton, where the river enters the *THAMES* Gravels, but does not pass directly into the *THAMES* at Barnes, but turns eastward and falls into that river opposite Fulham Palace. Artesian wells in the area of overflow occur in the parishes of Merton, Malden, and Mortlake, of a depth of 300 feet; none are in the Chalk, except Mr. Randall's, at Mortlake, which reached it at 315 feet from the surface.

River Wandle.

The drainage area of this stream is bounded on the west by the *Beverley* River; like it, the surface stream rises on the northern slope of the Chalk Downs of Banstead, along a line marked by the villages of Carshalton, Beddington, and Croydon, where a powerful chalk spring still issues near the church. The underground drainage of the Chalk area to the south is also received in this basin, and when in excess the springs in the dry valleys burst out. The permanent surface stream appears at, and a little above, the 100 feet contour, thence the *Wandle* descends by Mitcham and Tooting in a straight line to the *THAMES* at Wandsworth.

Of artesian wells, in the area of overflow extending over the parishes of Wandsworth, Streatham, Tooting, Mitcham, Morden, Merton, and Wimbledon, the oldest is the public well at Tooting Church, sunk in 1822. The deepest is that at Garratt Farm, Wandsworth, which is 365 feet deep, and probably 5 feet in the Chalk. The water rose 7 feet above the ground, and 43 above Ordnance Datum. In Mitcham parish the top of the Chalk varies from 110 to 256 feet below Ordnance Datum.

Croydon.—Population, 78,947; from four artesian wells, sunk in the Chalk, and bored to a depth below the surface of the ground 76, 106, 150, and 214 feet respectively, and pumped therefrom into three service reservoirs; 2,750,000 gallons (constant); rateable value, 326,851*l.*; Public Health Acts, 1848, and subsequent Acts.

Wimbledon.—*Acres*, 3220; population, 15,947; by the

Lambeth Waterworks (*THAMES*); intermittent; rateable value, General District Rate, 97,232*l.* 10*s.* A well at Hayden's Lane Station reached the Chalk at 160 feet from the surface, or 106 below Ordnance Datum; water rose 55 feet above Ordnance Datum, and 20 above ground. A well at Wimbledon Sewage Works did not reach the Chalk until a depth was reached of 277 feet from the surface, or 225 feet below Ordnance Datum; water rose to the surface 52 feet above Ordnance Datum.

CHAPTER XIII.

THE SOUTH-EASTERN THAMES BASIN.

DARENT BASIN (*CXXVI.*).

This basin has an area, with the Rivers *Ravensbourne, Cray,* and Gravesend district streams, of 314 square miles, of which Greensand and Gault occupy 30 miles, Chalk 254, and Tertiary deposits 30.

River Ravensbourne.

This river drains an area of about 77 square miles, of which Mr. Lucas estimates 21 square miles consist of Chalk; the Chalk in the remaining area is covered by Tertiaries. Its western watershed rises from the *THAMES* Gravels at Deptford, crosses the Woolwich Beds, and runs along the crest of the hill composed of London Clay above New Peckham, ranging in a south-south-westerly direction, by Nunhead Cemetery, Forest Hill Station (east of which it is 295 feet above the mean sea-level), Sydenham Hill, 365 feet, the Crystal Palace to Whitehouse Wood; here it trends to the south-east, and crosses the dry col between Croydon and Beckenham, connecting the valleys of the *Ravensbourne* and the *Wandle.* The lowest point of the col, half a mile south of Norwood Junction, is above 175 feet above the sea; from this point the line of watershed ascends the hillside above Addiscombe, reaching the Oldhaven Gravels, where the 200 feet contour line intersects the watershed, and the Woolwich Beds at the top of the hill at, and a little above, the 300 feet contour, passing over the Thanet Sands on the south side of the hill, and reaching the top of the Chalk at Combe Wood, which is slightly below the 300 feet contour; thence the watershed traverses a number of Tertiary outliers lying on the Chalk, forming a series of gentle eminences by Ballards, Selsdon, and Sanderstead, which village is above the 500 feet contour, so that the top of the Chalk between this point

and Deptford, a distance of 7 miles, has sunk or dipped at least 500 feet, or 71 feet per mile.

Following the watershed eastwards along the top of the Chalk Downs of Farley Court and Keston, where the top of the Chalk has sunk to 400 feet, it crosses the Oldhaven Beds at Cæsar's Camp, in which is Cæsar's Well, and turns eastward to Farnborough, whence it trends northwards, and commences to descend steadily; crosses the Lewisham and Tunbridge Railway at Crofton Court, near Orpington Station, at an elevation of 300 feet, the London, Chatham and Dover Railway at St. Paul's Cray Common, between the 13th and 14th mile-post from London, thence, by the Oldhaven Beds of Chislehurst, it trends north-west to Eltham. It passes on to the bottom of the London Clay at 275 feet, at Belmont Wood, and, after traversing it for a couple of miles, again reaches the Lower Tertiaries at Eltham Place, where the "*Cyrena* Beds" are well seen in the railway cuttings at 175 feet, so that the base of the London Clay has descended 100 feet in a northerly direction in that distance. From Eltham the watershed trends north-east to the top of Shooters Hill, north of the Greenwich and Gravesend road, which crosses the hill; the drainage falls directly into the *THAMES* at Charlton and Woolwich.

The Lower London Tertiaries crop to the surface along the escarpment ranging through Greenwich Park, Lower Charlton, Woolwich, Plumstead, and Erith, the Chalk for the most part being seen at the base between the two last-mentioned localities; it is thrown down under Plumstead Marshes by an east and west fault, bringing in Oldhaven Beds north of Abbey Wood. A similar fault, or a continuation of that just described, but traversing a south-westerly direction, ranges at the foot of Greenwich Park, crosses the *Ravensbourne* Valley, and extends as far as Sydenham Hill.

In the upper portion of the *Ravensbourne* Basin the rainfall is absorbed by the Chalk, and no actual stream is ordinarily seen at the surface; its most western feeders rise between Norwood Junction and Elmers End Railway Station, at 170 feet, on the London Clay at Langley Park, on the

Oldhaven Beds at a similar elevation. Its southern feeders at Hayes on the latter deposits, at 200 feet above the sea, and at Cæsar's Well, also, in the Oldhaven Gravel, at 425 feet above the sea.

The following towns and villages are within the *Ravensbourne* watershed besides those mentioned above:—Addington, Wickham, Breux, Bromley, Beckenham, Sydenham, *acres*, 1623; population, 26,070: Lewisham, *acres*, 3781; population, 19,859: Lee, *acres*, 1608; population, 21,558: Kidbrook, and Greenwich.

London Water Supply—Kent Chalk Wells.*

The *Kent Water Company* supplies more than 42,000 houses in the south-eastern portion of the Metropolis and suburbs with upwards of 9,000,000 gallons of water from deep wells in the Chalk. The Commissioners lay great stress on the purity of the deep-well waters without subsidence or filtration, the worst, that of Charlton, being less polluted than the *THAMES* water after filtration.

Locality.	Depth.	Yield. Mill. Gallons.	Total Solid Impurity.	Chlorine.	Hardness.			Remarks.
					Temp.	Perm.	Total.	
	Feet.							
Deptford New Well ..	250	4½	42·94	2·50	20·1	9·6	29 7	Clear.
„ Bath Well	..	1½	35·44	2·30	18·6	8·0	26·6	„
„ Garden Well	..	4½	40·96	2·40	20·2	8 6	28·8	„
Shortlands	..	1½	30·64	1·60	19·3	4·6	23·9	Turbid.
Crayford {(2 wells, 1 used).}	150	9/10	35·20	2·25	20·3	5·4	25·7	„
Belvidere	70	2/10	40·52	3·35	10·8	11·6	22·4	„
Plumstead	500	7/10	50·80	4·60	16·8	13·8	30·6	„
Charlton {(2 wells, 1 used).}	?	6/10	92·80	19·70	21·3	21·3	42·6	„

The water stands in the shaft at an average height of 10 to 20 feet above Ordnance Datum; the level of the water at Deptford is only reduced 50 to 60 feet by rapid pumping. The late Mr. W. R. Morris, M. Inst. C.E., stated, in 1869, that the then yield of 7,000,000 gallons daily could be increased to 10 by the existing machinery, but the wells were capable of yielding double that amount. The Rivers Pollution Com-

* See also pp. 179, 182, 194, 243.

mission states "the supply of such water, either softened or unsoftened, to the Metropolis generally, would be a priceless boon, and would at once confer upon it absolute immunity from epidemics of cholera," and that increase of capital should only be granted to existing companies on condition that it was expended on work necessary for the supply of this palatable and perfectly wholesome beverage.

The following journal of the strata passed through by the deep boring of the Metropolitan Board of Works has been drawn up by Mr. Whitaker, of the Geological Survey:—

Crossness Junction Outfall Works, New Well.

		Feet.	
	River drift-gravel .. .. to	39	
[Woolwich Beds 47 feet.]	Very hard stiff blue clay	2½	
	Stiff yellow clay and sand layers	2½	
	Hard sand, with layers of tenaceous clays of various colours	7½	
	Hard sandy clays .. .. .. Over	8½	
	Very stiff hard clay .. .. .. Nearly	6	
	Dark greensand	4	
	Dark greensand with pebbles of various sizes .. .. Over	4	
	Green clayey sand, with and without pebbles	12	
[Thanet sand 51 feet.]	Thanet sand .. .. Over	50	
	Green flint .. .. Nearly	1	
	To Chalk	137	
	Chalk (should be more?)	631	
	Upper greensand (should be less?) ..	65	
	Gault (phosphate at bottom, specimen at Board Works)	170	(1003)
[Red Rocks.]	Sandstone, very hard	13	
	Grey sand	4	
	Red marl rock	18	
	Grey sand rock	4	
	Red marl with blue vein	3	
	Grey marl	2	
	Grey sand rock	11	
	Red marl with blue vein	2	
	1877	1060	

Mr. Whitaker* points out the strong improbability of the

* 'Guide to Geol. of London.' In Mem. Geol. Survey.

bottom beds at Crossness and Kentish Town being part of the Old Red series, when rocks of true Devonian type occur at so short a distance from them as Meux's Brewery, which in fact is between the two; that two types of one geological system should occur in the same limited area seems well-nigh improbable. I have to thank Mr. Keates, F.C.S., of the Metropolitan Board of Works Office, for an opportunity of examining the red rocks from the Crossness well, and have no doubt that they are referable to the Keuper Marls.

Beckenham, (Kent, Extra Metropolitan).—*Acres*, 3880; population, 6090; *Lambeth and Kent Water Companies* (I.); rateable value, 95,000*l.*

Bromley.—*Acres*, 4706; population, 10,674; private wells, largely fed by surface water. *N.B.*—The *Kent Waterworks* mains are laid throughout the district, and the supply at the disposal of the inhabitants. (Partly c.); rateable value, 89,406*l.*; the Kent Waterworks Act, 1809, and 27 & 28 Vict. c. 146, and the Acts incorporated.

Greenwich.—*Acres*, 1741; population, 46,623. Supply from *Kent Waterworks.* Rainfall observations have been taken at the Royal Observatory since 1815, but the records prior to 1841 are uncertain. The following monthly averages for 1841 to 1879 are calculated by Mr. W. C. Nash, F.M.S.:—

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total.
Max. ..	4·35	4·03	4·05	4·31	4·37	5·80	5·81	5·38	4·12	5·95	6·00	5·76	34·01
Mean ..	2·12	1·44	1·47	1·66	2·07	2·05	2·40	2·49	2·25	2·82	2·23	1·76	24·76
Min. ..	0·55	0·20	0·17	0·09	0·30	0·30	0·27	0·45	0·16	0·76	0·42	0·31	16·38

Mr. G. J. Symons,* F.R.S., points out the support these tables give to the theoretical proportions taken by engineers, "that the wettest year in a long record will be one-third greater than the mean. The driest year will be one-third less than the mean. The driest group of three consecutive

* 'British Rainfall in 1880.' London, 1881.

years will be one-sixth less than the mean." Applying this to the table for 1841 to 1879—

	Theoretical. In.	Fact. In.	Difference. In.
Wettest year	33·01	34·01	+ 1·00
Driest year	16·51	16·38	− 0·13
Driest 3 consecutive years	20·63	20·71	+ 0·08

At 155 feet above the sea, the rainfall recorded by Sir George Airy, K.C.B., was 31·36 inches in 1879, and 29·68 inches in 1880.

Deptford.—*Acres*, 1685; population, 84,641. Supply from *Kent Waterworks*.

Woolwich registration sub-district consists of the following sub-districts:—

	Acres.	Population.
Charlton	1986	10,930
Woolwich Dockyard	412	17,650
Woolwich Arsenal	714	18,950
Plumstead, West	349	14,009
Plumstead, East	3039	19,243

River Cray.

This stream is 9 miles in length; its western watershed is formed by the eastern boundary of the *Ravensbourne* already described; its southern margin traverses Chalk hills and dry valleys 400 to 500 feet above the sea. The valley between Down and Orpington falls 200 feet in 3 miles, or 70 feet per mile, the top of the Chalk appearing about the level of the 200 feet contour. Powerful springs rise in the Chalk at Orpington, discharging 3,500,000 gallons a day, feed the stream used at the mills at that place, and lower down the stream at St. Mary's Cray and St. Paul's Cray. At Foot's Cray the base of the Tertiaries has descended another 100 feet in a distance of 2 miles, or 50 feet per mile. The fall per mile is still further lessened in the next 3½ miles by North Cray, Bexley, and Crayford, partly because, through the valley trending to the north-east, this distance is only equivalent to 2 miles of the full northerly dip, which would give the fall due to full dip of about 37 feet per mile. This magnificent water is hopelessly polluted by

the refuse of the paper-mills, and the *Kent Water Company* have had to lay pipes up the valley against a head of 100 feet. The Bexley registration sub-district contains 12,541 acres, with 24,137 inhabitants.

RIVER DARENT.

The *DARENT* rises within the Weald watershed, breaches the Chalk escarpment, and flows through the Chalk country by Shoreham, Lullingstone, Eynsford, Farningham, Horton Kirby, Sutton-at-Hone, Darent, and Dartford. The Tertiaries of the Lower Basin are only of minor importance in this watershed, and only cap the tops of the hills, the strike of the high ground. It drains about 167 square miles, including the *Cray*, of which Chalk occupies, according to Mr. Lucas, 64 square miles in the *DARENT* Basin, and 26½ in that of the *Cray*, or 100 square miles in all.

The River *DARENT*, gauged at Shoreham by Captain Vetch,* averaged 2080 cubic feet per minute, or 19,000,000 gallons per day. The area here drained is stated by Mr. Topley † to be 50 square miles, or about 41·6 cubic feet per square mile of drainage, excluding the strong Chalk springs of Orpington; but, even deducting this latter quantity, the volume is much above the average, and is probably due to the strong springs of the Lower Greensand. Mr. Topley estimates that 16 square miles of Lower Greensand drains into the *DARENT* west of Sevenoaks, which, with one-third absorption of 28 inches of rainfall, would give 6,000,000 gallons daily. Deducting springs, the whole of this amount passes under the Gault, as does the Lower Greensand rainfall of 11 square miles, east of Sevenoaks. In driving the railway tunnel west of Sevenoaks enormous quantities of water were met with in the Hythe Beds.

Professor Prestwich ‡ states that in sinking a well in the

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* 'Hughes' Treatise on Waterworks,' p. 45.

† 'Mem. Geol. Survey. Geology of the Weald,' p. 361. 1875.

‡ 'A Geological Inquiry respecting the Water-bearing Strata of the Country around London.' London: Van Voorst. 1851.

Chalk, near the edge of the escarpment at Knockholt, the workmen met with a cave, 30 feet long, 12 feet broad, and 18 feet high, of irregular shape, at a depth of 270 feet from the surface, at the bottom of which ran a stream of water.

SEVENOAKS.—*Acres*, 2115; population, 6288; *Sevenoaks Waterworks* (private incorporated Company); well supplied by springs from the Kentish Rag; 150,000 gallons (c.); rateable value, 31,643*l.*

SOUTHBOROUGH.—*Acres*, 1660; population, 3870; wells; rateable value, 19,647*l.* 10*s.*

DARTFORD.—*Acres*, 4300; population, 10,567; the *Kent Water Company's* district.

ERITH.—Population, 9723; the *Kent Waterworks Company* and private wells in chalk; 25 gallons per head (intermittent); rateable value, 37,540*l.*

Gravesend Streams.

The eastern boundary of the *DARENT* Basin does not trend directly to the *THAMES* at Gravesend, but turns westward by Swanscombe Park and Telegraph Hill to Dartford. The Roman road of Watling Street is nearly coincident with it. The district lying north of the watershed, occupying about 70 square miles, drains directly into the *THAMES*. The underground drainage also of the Chalk is towards the sea, and includes, according to Mr. Lucas, that of 17 square miles of the *DARENT* Basin. It consists of Chalk capped by Thanet Sands here and there, and includes Stone, Greenhithe, Swanscombe, Northfleet, and Gravesend.

GRAVESEND.—*Acres*, 1256; population, 23,375; the *Gravesend and Milton Waterworks Company;* pumped from deep well into reservoir; 152,738 gallons (intermittent); rateable value, 91,315*l.*; the Gravesend and Milton Waterworks Company's Act, 9 Vict., Session 1846.

The ships at the port get their supply of water from a 2-inch "Abyssinian" tube well, driven 50 feet through contaminated water to a pure spring.

NORTHFLEET. — *Acres*, 3980; population, 8577; the *Gravesend and Milton Waterworks Company's* works and wells (intermittent); rateable value, 38,969*l.*; the Gravesend and Milton Waterworks Company's Act, 9 Vict., Session 1846.

"Abyssinian" tube wells supply 60,000 gallons to the Cement Works at Northfleet.

RIVER MEDWAY (CLXXXI.).

Length, 44 miles; area, with tributaries, 630 square miles, of which 566 miles are within the Weald, and 64 without it. Of the area within it, 224 square miles consist of Tunbridge Wells or Hastings Sands, 355 of Weald Clay, 37 of Greensand and Gault. Of the area north of the Weald, 42 miles are occupied by Chalk, and 22 of Chalk overlaid by Tertiaries.

All important tributaries of this river rise and fall into the *MEDWAY*, in the Weald area. The *Eden* is 13 miles long, and rises near the *Mole* watershed, east of Reigate; on it are Edenbridge and Lingfield.

River Tun.

The River *Tun* rises near the Weald anticlinal watershed, near East Grinstead, adjoining the *Eden*, and at Penshurst becomes the *MEDWAY*, which flows across the Tunbridge Wells Sands to Tunbridge, where it passes on to the Weald Clay, at which point the river becomes navigable, and is 80 feet above the sea. It traverses the Weald Clay for 8 miles, receiving the rivers *Teise* and *Beult* on its right bank. The *Teise* is 13 miles long, rises in the Tunbridge Wells Sands south of Lamberhurst, which is 139 feet above the sea, and drains the country around Cranbrook and Frittenham, with a rainfall of 24·5 inches.

River Beult.

The *Beult* is 21 miles long, entirely drains a Weald Clay district, including the district around Staplehurst, which has

a rainfall of 26·5 inches. Near the point where the river joins the *MEDWAY*, the latter enters on the belt of Lower Greensand which surrounds the Weald, and lies at the foot of the Chalk escarpment. At Maidstone, which is on the Greensand tract, the river has descended to 22 feet above the sea, and a few miles further north passes through the Chalk escarpment by Rochester and Chatham, where it reaches the Tertiaries.

Crossing the watershed of the *Darent* and *MEDWAY* basins, Mr. Topley points out, the valley of the Plaxtole is cut down to the Atherfield Clay, which carries off a large amount of the Lower Greensand rainfall, as does the stream running along the anticlinal line north of Offham and West Malling. Strong springs also carry off a portion of its waters at Mereworth, and in the valley of the *MEDWAY* from Wateringbury to Maidstone, as well as the strong springs of Bradbourn and St. Leonards. The total amount so carried must be large, but the quantity absorbed by 40 square miles, and carried north under the Gault, must be considerable. East of the *MEDWAY* the case is different, springs not only being numerous, but a stream flowing through the Loose valley falls 180 feet in 2 miles, turns twelve mills, and carries a large volume.

The chalybeate springs have often been described. Mr. Topley* gives a recent analysis by Mr. J. Thomson, who states "its chief characteristic is its extreme purity, its principal constituent being iron held in solution by the agency of free carbonic acid." The temperature is always 10° C. (50° Fahr.), and the yield 3·13 to 3·33 gallons per minute. Of sulphate of lime there is 2·1000 grains to the imperial gallon, of carbonate of iron 3·9123 grains, of chloride of sodium 3·1780.

Anticlinal rolls in the south-east of England have exposed the Atherfield Clay at the base of the Lower Greensand in some valleys, which throw out very powerful springs at the

* 'Memoirs of the Geological Survey. The Geology of the Weald.' By W. Topley.

base of the Hythe Beds around Riverhead and Bradbourn, and water was met with in enormous quantities in driving the railway tunnel west of Sevenoaks, it being calculated that no less than two-thirds of the rainfall (28 inches) of this area sinks into the ground.

Mr. Topley states the "success of this scheme of tapping the Lower Greensand depends evidently upon whether or not there be any great quantity of water in that formation. It is highly probable that to the north of London much of the water which falls on the Lower Greensand passes under the Gault to the south, towards London, and may be obtained by boring. But it is not from this side of the London Basin that the greatest supply is expected. Whether or not the Lower Greensand on the south of London will furnish a sufficient supply is a difficult question, and one that can only be satisfactorily solved by actual borings in that direction."

Only so much water as falls as rain *on* the Lower Greensand can avail for underground water supply. The small quantity falling on the Gault, and running over it into the Lower Greensand, Mr. Topley considers unimportant.

An examination of one of the sections of the Geological Survey drawn across the Weald from north to south, or of the model * of the district prepared by Messrs. Topley and Jordan, at once discloses the fact that the Weald district, so far from being a valley, is traversed by a central ridge running from east to west, and actually rising above the level of the North and South Downs, limiting the so-called valley. It will also be noticed that this central ridge, rising to 803 feet at Crowborough Beacon, is the line of the anticlinal axis, tilting the strata in opposite directions, and constituting the natural watershed between the streams of the *THAMES* Basin and those of the South Coast. If the lines of original thickness of the strata be restored over the present surface of the ground, on the section above referred to, it will be seen that the upper surface of the Chalk must have formed a hill about the height of Helvellyn over the

* Published by Mr E. Stanford, London.

ground traversed by the axis, from which it inclined with an exceedingly gradual slope to the north and to the south.

Summer Discharge.	Area in Square Miles.	Cubic Feet per Mile.	Discharge per Square Mile.	Representing Rainfall per Annum.	Total Average Rainfall.
The Medway, driest seasons (*Rennie*, 1787)	481·5	2209	4·59	1·04	
Ditto, ordinary summer run (*Rennie*)	..	2520	5·23	2·19	

The water-line in the high Chalk hills between Maidstone and Sittingbourne is comparatively low, hydrostatic pressure is small, and the fissures are soon exhausted. Mr. Bland* in 1832 described a well 303 feet deep, with 37 feet of water, which was drained dry by emptying another well, a mile distant, the water-level standing in the exhausting well only 27 feet lower than in the exhausted well.

Rochester.—Population of Urban Sanitary Authority, 21,590. There are two Companies, the *Brompton, &c. Waterworks Company* and the *Strood Waterworks Company;* the former incorporated by special Act, the latter a limited Company. In the case of the *Brompton, &c. Waterworks Company*, the Act provides that the water to be supplied shall be under pressure, but need not be constantly laid on; and as to the portion of the city supplied by that Company, it is now turned off at night. As to the *Strood Waterworks*, it is turned off at night. Rateable value, 46,612*l.* 15*s.* (net). The Corporation have been recently considering as to the supply from the *Strood Waterworks Company* being sufficient for their district, and as to whether they should not at once take steps for purchasing the existing *Strood Waterworks*, and themselves undertaking the supply. This question is still under consideration, and will be disposed of without delay. The supply from the other Company (the *Brompton, &c. Waterworks Company*) is quite sufficient.

* 'Phil. Mag.,' New Ser., vol. xi. p. 88.

CHATHAM—Population, 26,385; almost entirely by the *Brompton, Chatham, Gillingham, and Rochester Waterworks Company;* there are also a few private wells; intermittent; rateable value, 57,781*l.*; 23 Vict. c. 38.

GILLINGHAM.—*Acres,* 4317; population, 20,802; *Brompton, Chatham, and Gillingham Waterworks Company;* wells and adits in Chalk; reservoir; intermittent; rateable value, 42,454*l.*; the Waterworks Company to turn on full force of water at night in case of fire.

WROTHAM.—*Acres,* 8879; population, 3296; wells and pumps; draw wells from the Chalk; constant; rateable value, 19,093*l.* 5*s.* 2*d.*

TUNBRIDGE (Kent).—*Acres,* 1200; population, 9340; *Tunbridge Waterworks Company;* two large wells, 12 feet diameter; supply constant; rateable value, 40,000*l.* at the present time.

TUNBRIDGE WELLS (Kent and Sussex).—*Acres,* 3351; population, 24,309; springs;* collecting wells, thence by main to reservoirs, storage and service; from 260,000 to 350,000 gallons, according to the time of year; intermittent; rateable value, 156,926*l.*; the Tunbridge Wells Water Act, 1865, 28 & 29 Vict. c. 204.

MAIDSTONE.—*Acres,* 4632; population, 29,638; springs from Chalk; about 30,000 gallons (c.); rateable value, 109,647*l.* 10*s.*; 42 Geo. III. c. 90 (Local); 31 Geo. III. c. 62 (Local).

ISLE OF SHEPPEY and NORTH KENT STREAMS (LXXXII.).

Area 157 square miles, of which 84 are Chalk and 73 Tertiary. The mainland tract of this area is bounded west by the *MEDWAY* watershed, south and east by the watershed of the *GREAT STOUR,* which first runs along the top of the Chalk escarpment overhanging the Weald, and then turns abruptly northwards, running parallel to the *STOUR,* which

* The minimum yield of the springs in 189 days of drought in 1874 was 206,064 gallons per day; the maximum in 1875, a wet year, was 816,700 gallons, according to Mr. Brentnall, C.E.

breaches the escarpment, and flows down the dip to Canterbury. Within the North Kent basin are Charing, Milton, and Faversham. The rainfall is 22·3.

At Sheerness Dockyard there are two wells penetrating the Thanet Sand through 350 feet of London Clay. One well is 330 feet deep, with a boring carried 120 feet further. Below the clay is light sandy loam, dark sand or clay, and dark stiff clay to 400 feet, then sand and clay to pebbles. When the supply of water comes in, all top waters are excluded. Thirty tons of water are pumped from this well for 7 hours a day. The old well is 450 feet, the Waterworks well 384 feet. The temperature at both is 16°·7 Cent., or 62° F.; the old well has of solid impurity 61·10, of hardness 8·1, of which 3·6 is permanent, of chlorine 9·10.

Oldhaven (*and Blackheath*) *Beds.*—This name was proposed by Mr. Whitaker * for the sands and pebble beds occurring between the London Clay and Woolwich Beds in Kent, the basement bed of the former sometimes overlying them. The series of much-rolled flint pebbles, formed, it is believed by Mr. Whitaker, on a shoal, where none but much abraded flints could reach, at the base is fine current bedded quartzose sand, the whole series in East Kent only reaching a thickness of 20 feet. Though in East Kent there is no accidental unconformity of the Oldhaven Beds on the lower Woolwich Beds, in "outliers far out in the Chalk tract" the Oldhaven Beds rest on the bare chalk.† In the Canterbury district sandy brown iron-ore (Limonite), occasionally running into brown hæmatite, sometimes occurs at the base of the Oldhaven Beds for about 5 miles around Blean and Rough Hills.

In the Tertiary district around London, the London Clay consists of tenacious brown and bluish-grey clays, with layers of septaria, large irregular-shaped nodular masses of clayey Limestone, with divisions or septa of calc spar or arragonite.‡

Mr. Whitaker describes the brown colour near the surface

* 'Quart. Journ. Geol. Soc.,' vol. xxii. p. 412.

† 'Mem. Geol. Sur.,' vol. iv. p. 240.

‡ Prestwich in 'Quart. Journ. Geol. Soc.,' vol. vi. pp. 253–4

as one "of decomposition; the protosulphate of iron that gave the bluish tint peroxidating by exposure to atmospheric action;" and hints that the septaria are also due to infiltration.

The sandy clay with pebbles, or basement bed of the London Clay, extends over a very large area; the pebbles are rolled flint, generally black, but occasionally white-coated, and are traversed by a minute system of cracks filled with thin films of oxide of iron or ferruginous clay.

SHEERNESS (Kent, Extra Metropolitan). — *Acres*, 940; population, 13,941; well, upper sand, 348 feet from the surface; 12 gallons per head, new works will give 40 (intermittent); rateable value, 27,170*l.*; the Local Government Board.

HERNE BAY.—Population, 1594; bed of gravel overlying the London Clay formation; artesian well; 45,000 gallons (intermittent); rateable value, 6759*l.* 15*s.*; 30 & 31 Vict. (1867), c. 112.

FAVERSHAM.—*Acres*, 495; population, 8756; *Faversham Water Company*, and from wells and springs; Water Company has two reservoirs, from whence water is delivered by gravitation; average quantity used daily is 140,000 gallons (constant); rateable value, 27,819*l.*

MILTON-NEXT-SITTINGBOURNE.—Population, 4185; public pumps, wells, and fountains; rateable value, about 14,000*l.*

SITTINGBOURNE.—*Acres*, 1013; population, 7884; Waterworks at Keycoll Hill; well bored to 400 feet in chalk rock; 40,000 gallons in summer, and 25,000 gallons in winter (constant); rateable value, 21,773*l.*; the Public Health Acts.

A spring in the chalk at Sittingbourne formerly gave sufficient water for moving power to a paper-mill, but in 1835 it partially failed, and recourse was had to boring, and a plentiful supply obtained.

CHAPTER XIV.

OLD THAMES STREAMS.

STREAMS formerly falling into the *THAMES* Estuary, through lands, since denuded, lying north of the Weald anticlinal:

GREAT STOUR.

Length, 42 miles; area, 337 square miles, of which 72 square miles are within the Weald, and 265 outside it. Of the former area 11 square miles consist of Weald Clay, and 61 of Greensand and Gault. Two streams meet at Ashford, running in the same line, then, flowing in opposite directions, they traverse the Weald Clay, and coincide with its strike; uniting at Ashford, they form the Great *STOUR*, which flows in the direction of the dip, but at a smaller angle, passing in succession across the outcrops of the Lower Greensand, Gault, Upper Greensand, through a gorge in the Chalk escarpment, and then across that formation by Canterbury, passing on to the London Clay, maintaining its trend until it reaches the point where the *Little Stour* falls into the *STOUR*, when it turns eastward, following the strike of the Chalk, falls into the sea between Sandwich and Ramsgate, north of the Tertiary tract filling in the Great *STOUR* depression, and extending from Herne Bay to Pegwell Bay. The Chalk reappears at the surface at Ramsgate and Margate, and forms the Cliffs of the North Foreland.

At Canterbury the water supply is derived from two borings, 11 feet apart, 24 inches in diameter, 490 feet deep, lined with cast-iron tubes to 36 feet in the Chalk, at a distance from any house, capable of yielding 60,000 gallons hourly. The quality is stated by the Rivers Pollution

Commission to be unsurpassed by that of any other in Great Britain. The works, like those of Tring and Caterham, were carried out by Mr. S. C. Homersham, C.E. 110,000 gallons, in 1874, were softened by addition of 11,000 gallons of lime water, at a cost of 27*s.* per 1,000,000 gallons, reducing the total solid impurity from 33·60 to 11·94, the hardness from 2·36 to 4·9, and every trace of organic matter was removed.

At Deal the Rivers Pollution Commission reports the well in the Market Place so polluted as to be more fit for application to the land than for drinking. The town supply is, however, excellent, though hard for washing, derived from chalk borings 115 feet deep, of a temperature of 11°·3 Cent., of a hardness of 26·3, of which 6·1 is permanent. A tube well through 11·6 feet of brick-earth, gravel, and chalk, passes through salt-springs at 18 feet and 116 feet, and a fresh-water spring at 45 feet. At Dover the waterworks well in the chalk is 220 feet deep, that in the Castle, 367 feet; both of about 23° of hardness.

Tenterden.—*Acres,* 8869; population, 3620; private wells; rateable value, 18,895*l.*

Ashford.—*Acres,* 2785; population, 9693; from springs, the property of the *Ashford Waterworks Company,* and from private wells; rateable value, 43,123*l.* 15*s*; private Company; no Act of Parliament.

Canterbury.—Population, 21,701; pumped from underground springs at a great depth, and supplied direct from the mains; also pumped into a reservoir to provide for the supply when pumping cannot be carried on; not natural reservoirs; wells; chalk water softened by Dr. Clark's process; 316,000 gallons (constant); rateable value, about 74,000*l.*; by 29 & 30 Vict. c. 99. Rainfall in 1879 at Bridge Street, 52 feet above the sea, 31·84 inches.

Margate.—Population, 15,889; from wells; reservoirs; 700,000 gallons (constant); rateable value, 68,000*l.*; by Act of Parliament, 1857, and Provisional Order.

Ramsgate.—*Acres,* 260; population, 22,605; deep wells in the Chalk only; 400,000 gallons (intermittent); rateable

value, 96,649*l.*; 5 Will. IV., "An Act for the better supplying with water the parish of Ramsgate, and the neighbourhood thereof, in the county of Kent," and "The Ramsgate Local Board Act, 1877."

Rainfall at the Vale, 90 feet above the Sea.

1876.	1877.	1878.	1879.	1880.
23·68	29·49	30·47	25·99	29·56

During the last five months of 1879 very little rain fell, and in the first five months of 1880 only 3·88 inches fell; while in June there was a precipitation of 3·83, and in October of no less than 7·92.

Deal.—*Acres*, 1159; population, 8422; partly from wells in Chalk and reservoirs of a Company incorporated by an Act, and partly by private well supply; average about 12 gallons per head (c.); rateable value, 25,904*l.*; 3 & 4 Vict. c 113.

Sandwich.—*Acres*, 756; population, 2846; principally from the *Delph*, taking its source about 6 miles off, running through the town; there are town pumps which draw from wells (c.); rateable value, 9,330*l.*

Walmer.—*Acres*, 1019; civil, 2437, military, 1379—total, 3816 in 1871, 4309 in 1881; partly from a Company incorporated by an Act, and partly by private well supply; average about 12 gallons per head (c.); rateable value, 12,643*l.*; 3 & 4 Vict. c. 113.

STREAMS: DOVER TO DUNGENESS (CLXXXIV.).

Area, 88 square miles, of which 58 miles are within the Weald area, 34 consisting of Tunbridge Wells Sands, 13 of Weald Clay, and 11 of Greensand and Gault. The 30 miles lying outside the Weald are entirely occupied by Chalk, capped with an ancient Gravel, which has been shown to be the wreck of the Lower London Tertiaries. The cliffs rise to a height of 400 to 500 feet, and include the well-known

Abbott's and Shakespeare's Cliffs; the top of the latter was blown off by the Royal Engineers some years ago, and the former is penetrated by the tunnel of the South-Eastern Railway.

The numerous wells sunk at or near the sea coast, as that at Worthing, 400 feet deep; Margate, 374 feet of Upper Chalk; and at Dover Castle, prove the pressure of ocean water is not sufficient to penetrate the strata, which is still further supported by the dryness of collieries and copper mines worked under the sea, and the plentiful supply of fresh water obtained in the artesian wells sunk in the sea at the Spithead Forts.

If the plane of saturation by artificial means were lowered, then fissures or outlets which allow the escape of fresh water at or beneath the sea-level would no longer have sufficient head or pressure to force back the sea-water, and the sea would flow in. This has occurred at Calais, where, in an unsuccessful boring for water, a brackish stream was met in the Upper Chalk at 160 metres, or 70 feet, and Palæozoic rocks at 336 metres. These latter rocks in France and Belgium, with their productive coal-basins, are protected from the water in these exceedingly porous beds of Upper Chalk by the very impermeable Chalk Marl, which contains a large proportion of argillaceous matter and silica.

At Folkestone above 6,000,000 gallons are daily delivered, derived in winter from Chalk springs, which in summer diminish in volume, and the supply is taken from wells sunk through the Gault to the Lower Greensand, which are capable of yielding 500,000 gallons daily. The water is very hard, no less than 32°, but of a character that would be reduced to less than 8° of hardness by Clark's process, which is now adopted at various other places with great success for a similar class of water.

It is a curious fact that these hard spring and well waters, though clear and bright when first obtained, become covered with a confervoid growth when exposed to the sunlight in open reservoirs.

Professor Prestwich,* F.R.S., believes that, where the ridge of an anticlinal curve in a water-bearing stratum is lower than the outcrop of the bed, the water ascends the curve, which acts as a syphon, there being no communication with the surface, and drains off all the water between, and the spring ceases to flow until recharged, which explains the origin of the intermittent springs of Lavant, in Sussex; the Bourne, near Croydon; and several at the foot of the Chalk Downs, at Folkestone, in Kent.

In the Folkestone district,† after a careful study of the Chalk for some years, I think there is a tendency for joints and fissures to disappear in depth, and the lower beds to be more compact and homogenous; powerful springs like that of the Lydden Spout are rare; the water obtained from the deep wells of the various farmhouses on the Downs south of Dover draw upon an underground sheet of water travelling down the dip with an exceedingly slow movement, and saturating the lower beds to the extreme limit of their permeability. This surface of saturation is but little above the sea-level in Eastweir Bay, and eventually dips beneath it, and fresh water may be seen issuing between tide-marks on the shore.

The fact that the fissures are rarer and joints less open as lower levels are reached makes it exceedingly improbable, even if the sea-bottom of the Straits of Dover consisted of bare Chalk, which for the most part is not the case, that any

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* 'A Geological Inquiry respecting the Water-bearing Strata of the Country around London.' London: Van Voorst. 1851.

† The following levels are taken from the Ordnance Survey Level Book:

First milestone from Folkestone towards Dover	412·840
Second milestone	516·135
Opposite Royal Oak	450·258
Fifth milestone	418·123
Folkestone Church	114·053
Zero of Dover Tide Gauge	11·40
„ Folkestone „	11·40

The highest spring-tide mark at Dover was 21·91 on their gauge, and the lowest low-water mark 2·09 on it.

fissures occur which might conduct the sea into the workings of the proposed Channel Tunnel, for which the preliminary headings are now making good progress, though there can be no doubt that, the operations being carried on below the limit of *permanent saturation* of the Chalk, large bodies of water will be met with.

But this is no insuperable difficulty, for a tunnel for sewage works at Brighton has already been constructed beneath the sea-level by Sir John Hawkshaw, and no less than 8600 to 10,000 gallons of water were pumped per minute by 12 pumps, worked by engines of 150 horse-power. In the Channel Tunnel it is proposed to provide for 2000 horse-power; the approach to the tunnel will penetrate the White Chalk at a gradient of 1 in 80, and on reaching the Grey Chalk beneath, in which it is proposed to drive the tunnel, the water-bearing beds will doubtless be left behind.

Upper Greensand.—In Eastweir Bay the beds lying between the Chalk and the Gault are thin, and practically form the base of the former. At Aylesford Mr. Whitaker describes only 18 inches of Marl sand on this horizon. Green sandy beds continue westward to Otford; these beds are referable to the "Chloritic Marls" of Prof. Edward Forbes. West of Westerham harder beds come in of "firestone" and "malm rock," which continue and increase in importance by Godstone, Merstham, Reigate, Guildford, Farnham, and Selborne; plentiful springs are thrown out by its upper beds.*

Gault.—This formation I found† to be 130 feet thick at Folkestone, and to be capable of division into 11 beds or zones characterized by distinct organisms; the first and eighth zones consisting of phosphatic seams, the upper seam dividing the Upper Gault from the Lower Gault, the lower seam the latter from the Folkestone Beds.

Lower Greensand (Upper Neocomian).—Underlying the Gault in the cliffs at Folkestone are light-coloured sands,

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* W. Topley, in 'Geology of the Weald,' Memoirs of the Geol. Survey.

† 'Geological Magazine.' 1868.

with layers of silicious limestone and chert, in all about 90 feet in the cliffs and 100 feet in a well at Snodland. Beneath these "Folkestone Beds" are the "Sandgate Beds," a dark clayey sand and clay, throwing out a line of springs at the junction of the overlying sands. This was especially the case in Saltwood railway tunnel. In East Kent these beds are about 80 feet thick, thinning out to 30 feet west of Ashford and to 34 at Maidstone. Beneath these clays are the "Hythe Beds," described by Mr. Drew, as alternations in equal proportions of grey-blue limestone of close texture, called "rag," and drab-coloured impure sand. The thickness at Hythe and Lympne is about 60 feet. At Maidstone these beds, under the name of "Kentish Rag," contain Mr. Bensted's well-known Iguanodon quarry; the thickness there is about 80 feet. South-west of Dorking the beds increase to 240 feet or more, and contain more sandstones, the higher part being a Calcareous Grit called "Bargate Stone." At Leith Hill the Hythe Beds are 200 feet thick, and the same at Midhurst.

Beneath the Kentish Rag is the "Atherfield Clay,"* which throws out strong springs at the base of the Rag, west of Hythe. Its thickness there is 50 feet, proved in a shaft; westward it is thinner. The Sevenoaks railway tunnel is partly in this clay.

The waters from the Greensand and Hastings Sands are good and wholesome, though generally too hard for washing, but they can be softened by Clark's process. From the porous nature of these rocks, the organic matter contained in water passing through is readily oxidized. The protoxide of iron, nearly always occurring in the Greensands, has also a reducing effect on the nitrates and nitrites present in the water, removing their oxygen, and transforming a portion of their nitrogen into ammonia. Sometimes, also, the sulphates present are attacked, and sulphuretted hydrogen generated, the odour and flavour of which is observable when the waters

* The Atherfield Clay has recently been proved at Langton's Brewery, Folkstone, to be only 4 feet thick, resting on the Weald Clay at 152 feet from the surface. Mr. Lucas in 'Trans. Inst. Surveyors.' 1881.

are first drawn from the well, and which disappear with exposure to the air.

Dover (Kent).—*Acres*, 1262; population, total, 28,486; deduct military population otherwise supplied, 3148; works constructed by the Council; wells in Chalk, with headings, two reservoirs; high service, 500,000 gallons; low service, 1,000,000 gallons; average consumption, 1,000,000 gallons (c.); rateable value, 120,745*l.* in 1871; the Public Health Act.

Folkestone.—*Acres*, 4535; population, 18,717 (Municipal Borough); from springs issuing from the Chalk hills, and from wells dug in the Greensand formation; reservoir (I.); rateable value, 88,000*l.*; 11 Vict. c. 6; 18 Vict. c. 7; 21 Vict. c. 10; 27 Vict. c. 5; 34 Vict. c. 26.

Hythe.—Population, 4069; springs, reservoirs (c.); rateable value, 15,647*l.*; Hythe Improvement and Waterworks Act, 1874.

Sandgate.—Population in 1881, 1669; Honywood Spring, reservoir (c.); rateable value, 8375*l.*; authority of Local Government Board.

Rye (Sussex).—*Acres*, 900; population, 4220; a spring out of a lofty cliff; reservoir; steam pumping station, 6 free public pumps; rateable value, 11,500*l.*; Urban Sanitary Authority; no private Act.

River Rother.

Length, 27 miles; area, 312 square miles, wholly within the Weald, and entirely consisting of Hastings Sands, with the exception of two small tracts of Purbecks, formerly called "Ashburnham Beds." It rises above Mayfield, west of which place the watersheds of the *MEDWAY*, *Rother*, and *OUSE* basins meet. From this point the southern watershed coincides with the Weald anticlinal, which occurs much nearer the South Downs than the North, passing a little north of Battle and Hastings to the sea. The northern boundary trends east by Cranbrook and Tenterden to Hythe, between which and Lydd occur the Romney Marshes and Dungeness shingle, forming a tract of land

of comparatively modern formation, with an independent drainage system. Along the landward edge of the tract is the Hythe Military Canal, formed during the expectation of French invasion by Napoleon I., in connection with the line of Martello Towers which stud this coast, and are gradually being removed. The central watershed reappears on the opposite coast, between Boulogne and Ambleteuse, separating the River *Slack*, which flowed into the old River *Rother*, trending northward into the old *THAMES*, and thence to the *RHINE*, from the River *Liane*, which flowed south-west in what is now the English Channel.

The *Tunbridge Wells* Sands contain occasionally a subordinate bed of clay, of mottled colours, locally called "Cat's Brain," and the equivalent of the "Grinstead Clay" of the district to the west. The sands are about 150 feet thick, and rest on the "Wadhurst Clay," which is 160 feet thick in a well at Pellat Gate, Pembury, and 180 feet near Goudhurst. Near its base are horizons of clay, ironstone and Calcareous Grit, called "Tilgate Stone." Beneath these beds, at the Bodiham promontory, are the "Ashdown Sands"; the upper strata are massive rock beds; and beneath these are soft yellow sands, with grey loam beds. The beds are well seen in the Wadhurst railway cutting.

The Sub-Wealden Exploration.—This investigation was the outcome of the British Association Meeting at Brighton in 1872, it being then determined to carry out a suggestion of the Royal Coal Commission, that an experimental boring should be made in Sussex, in order to ascertain the thickness of the Secondary strata, and the nature of the underlying Palæozoic formation. Messrs. Godwin-Austen and Prestwich, in various papers and Reports, had clearly demonstrated the important fact that the Cretaceous rocks in Belgium and the North of France, instead of resting, as in England, upon an immense series of rocks, including the Purbecks, Oolite, Lias, Trias and Permian, lie directly on the Coal Measures, or still older rocks; as at Hames-Bucre, near Guines, where the Cretaceous rocks, 674 feet in thickness,

rest directly on the Devonian rocks, which was also the case at Leubringhem and Landrethun, while still older rocks were found at Caffiers, where Silurian slaty shales underlay the Cretaceous rocks, which also occurred under 300 metres of Tertiary and Cretaceous rocks; while at 1032 feet, at Calais, Carboniferous rocks occurred.

The Carboniferous Limestone, when last seen, is dipping south under the Oolite rocks in the northern part of the Bas Boulonnais, and Mr. Godwin-Austen pointed out that, south of this, a trough of Coal Measures may come in, which may possibly strike westwards under the Weald. Mr. Topley has shown that, though the great flexures, which traverse the South-east of England, are probably due to movements effecting the Palæozoic floor, yet the apparent tilt from the centre is partly due to inequalities of original deposition.*

Mr. Godwin-Austen pointed out that the coal basins of Westphalia, Aix, and Liége, and the rich coalfields of Mons and the North of France, formed separate portions of the same deep trough, and that the latter has been proved to within a distance of less than 30 miles from Calais; he argued with considerable force that this trough probably ranges westward, and extends under the various underlying formations across the South of England to Somersetshire.

This Belgium and North of France coalfield, running for 164 miles in an east and west direction, is only from 3 to 6 miles broad, though containing a thickness of 8000 feet of Coal Measures. It is bounded to the south by an ancient ridge of Early Palæozoic rocks, which crops to the surface in the Forest of the Ardennes, on the sides of which old mountain ridge the various Secondary formations were deposited, each newer one overlapping those previously formed.

In the Boulonnais, M. Souich found these various bands of Carboniferous and Devonian Limestones to range about W. 30° N. to W. 30° S.; and Professor Prestwich believes

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* Sir Henry De la Beche first suggested the prolongation of the Palæozoic rocks. 'Mem. Geol. Survey,' vol. i. p. 214.

that the crest of the old ridge will pass beneath the Cretaceous rocks of the South-east of England somewhere in the neighbourhood of Folkestone. Be this as it may, the position of the ridge must be evidently north of the greater part of the Weald of Kent and Sussex.

The Committee appointed by the British Association numbered amongst its members Professor Ramsay, the late Sir Philip Egerton, Sir John Lubbock, Sir John Hawkshaw, Mr. Godwin-Austen, Dr. John Evans, Professors Prestwich and Rupert Jones, and Mr. Henry Willett, Secretary and Treasurer. In August, 1873, 290 feet had been bored, and during the Bradford Meeting Mr. Peyton, F.G.S., communicated the discovery of *Lingula ovalis* in a core from 290 feet, proving the beds traversed to be Kimmeridge Clay. The Committee, dissatisfied with the slow progress made, accepted a tender from the Diamond Rock Boring Company on November 7th, 1873, for the completion of the boring to 1000 feet, which was reached on June 18th, 1874, at a cost of 1400*l.* for the additional 700 feet. Professor Ramsay and Mr. Willett then saw the Chancellor of the Exchequer, and urged the national importance of the undertaking, and a Treasury Minute was obtained, granting 1000*l.*, in 100*l.* grants, for every 100 feet bored, towards the sum required. Mr. Willett, who had energetically superintended the work, made another appeal for funds, stating that the Belgium Coalfield, reappearing in Somersetshire and South Wales, probably underlaid the South-east of England "at a depth of from 1500 to 2000 feet at Battle."

The diamond boring method was adopted in 1874, and Mr. Willett reports that the "crown" used was a ring of soft steel, 3½ inches in diameter, with 15 diamonds at the lower edge, of the variety called "Carbonado," from the Brazils, without lustre or cleavage planes. It revolved at a speed varying from 150 turns a minute in soft rock to 300 in hard rock. Water was pumped down the centre, and rose at the sides, carrying the detached matter in suspension, as is now the custom; but at that time "crowns" of 5 inches

diameter were spoken of as *large*, now "crowns" of a yard diameter are not unknown. The system, in 1873, was then new, and several men of the Royal Engineers were sent down to Netherfield to become acquainted with the method. At 612 feet, *two feet* were bored in ten minutes.

In 1874 Mr. Wm. Topley, of the Geological Survey, was sent down by Professor Ramsay and Mr. Bristow to watch the boring, and the following section is drawn up from his observations, aided by Mr. Etheridge, F.R.S., Palæontologist to the Survey.

	Feet.	
1. Surface Soil, and Blue Limestone and Shale, 48 feet		
2. Shales with Limestones, 108 feet (*Cypris subquadrata*, at 100 feet)		Purbecks, 282 feet.
3. *Gypsum* with Shale and Limestone, 37 feet		
4. Shaley Sandstone (Chert nodules and soft White Sandstone), 89 feet		Portland.
5. Kimmeridge Clay	751	
6. Sandstones and Shales	171	
7. Calcareous Grits and Shaley beds (Coralline Oolite)	186	
8. Blue Shale, with fossils and beds of limestone, nodules at base	267	Oxford Clay.
9. Dark Shale with fossils	144	
10. Hard grey limestone	16	
11. Dark Shale .. All bored	90	
	1906	

Mr. Topley's detailed examination of the cores commenced when the Kimmeridge had been penetrated a distance of 86 feet; he describes the clay as dark grey or blackish, showing no tendency to split, and being very hard from 330 to 350 feet from the surface, and again at 500 feet, and at 640 and 650; from 380 to 480 the clay is soft, laminated, and fossiliferous. Below 450 feet from the surface traces of petroleum are distinct, especially at 600, 604, 617, 622, and 651; in these parts fossils are scarce. The bedding is horizontal, but occasionally crossed by veins of carbonate of lime, especially at 480 and 594 feet. *Ammonites biplex*, *Modiola pectinata*, and *Lingula ovalis* occur throughout the

entire mass of the clay, but the largest individuals occur at the base. The characteristic Bas Boulonnais Lower Kimmeridge shell, *Gryphæa virgula*, appears to be absent. At Weymouth the Kimmeridge clays are 530 feet thick, and it was anticipated they thinned eastwards, instead of which they reached 750 feet; north-east of Rouen they are no less than 1000 feet.

In the Bas Boulonnais and in Dorsetshire the Coral Rag intervenes between the Kimmeridge and the Oxford Clays, but in some parts of England it is absent, as on the north and north-west of Aylesbury, Lincolnshire, and in the Lynn well, and this is the case at the boring; at 972 the Oxford Clay *Ammonites Sedgwickii*, Pratt, occurred, and at 999 *Ammonites Jason*, Rein, at 1000 feet *Ammonites Lamberti*, while the Kimmeridge *Gryphæa virgula* occurs at 950 feet; the boundary is therefore between 950 and 970 feet from the surface. At 960 a decided dip of 10° is shown in a Clay band, and after this, up to 972, several layers of fossils repeat this. Mr. Topley states the Sussex Purbecks reach a thickness of about 400 feet, consisting chiefly of shales, with bands of limestone on two horizons, an upper one called the "Greys," and a lower one called "Blues." The shales resemble stiff brown paper, and contain shells of *Cyrena*. Water flowing from old workings in the Greys is highly charged with bicarbonate of lime; that from the Blues is softer. The sub-Wealden boring commenced just below the main Blue. Springs were touched at 19 feet and 42½ feet from the surface, at which level the water stood permanently in the borehole.

The Gypsum Beds proved in the boring have been sunk to in a shaft at Archer's Wood on the estate of the Earl of Ashburnham, one of the early donors to the Committee's funds, and also on Mr. Egerton's estate, close to the boring, which will probably develop a new industry in this district.

Mr. Topley states the shingle flats which stretch out to sea at Dungeness and Langley Point are not without fresh water, notwithstanding that the level of the water in the

wells is affected by the tides. Wells at Langley, 50 yards from the shore, are only brackish in very dry weather.

POPULATION in the *THAMES* BASIN—SOUTH of the ESTUARY.

COUNTIES.	Population.	Density, acres to person.	Proportion of Population probably living in this group.	Population, about
CENSUS of 1871.				
Kent	847,507	1·2	$\frac{99}{100}$	839,031
Surrey	1,090,270	0·4	$\frac{5}{6}$	908,558
Hants	543,837	1·9	$\frac{1}{5}$	108,767
Berks	196,475	2·2	All	196,443
Wilts	257,202	3·4	$\frac{1}{5}$	51,440
Sussex	417,417	2·2	$\frac{1}{7}$	59,631
CENSUS of 1881.				
Kent	977,585	1 0	$\frac{99}{100}$	967,810
Surrey	1,435,842	0·3	$\frac{5}{6}$	1,196,518
Hants	593,487	1·7	$\frac{1}{5}$	118,697
Berks	218,382	2·1	All	218,382
Wilts	258,987	3·2	$\frac{1}{5}$	51,793
Sussex	490,316	1·9	$\frac{1}{7}$	70,045

CHAPTER XV.

SOUTH COAST RIVERS RISING SOUTH OF THE WEALDEN ANTICLINAL.

Sea Coast—Hastings to Beachy Head.

RIVER ASHBURN or OLD HAVEN (CLXXIX.).

Length, 8 miles; area, 121 square miles, of which 101 miles are within the Weald, consisting of Tunbridge Wells (Hastings) Sands, 66 miles; Weald Clay, 28 miles, largely concealed by the alluvium of Pevensey Level; Greensand and Gault, 7; outside the escarpment occur 20 miles of Chalk, terminating in the steep cliffs of Beachy Head, 564 feet in height, west of Eastbourne.

Fairlight Clays form the base of the "Hastings Beds." They consist of alternations of shale, clay, and sandstone bands with fish remains, reaching a thickness, according to Messrs. Drew and Gould, of 286 feet at the Signal House, Fairlight. These clays have been found to reach 330 feet at Bachelor's Brewery, Rye. Sections occur in the Ore railway tunnel. The clays were 333 feet at *Hastings Waterworks*, overlaid by 145 feet 9 inches of *Ashdown* Sand, and 16 feet 9 inches of *Wadhurst* Clay. A borehole at the Pelham Baths, Hastings, commenced in the Ashdown Sand, and penetrated clays; water was found at 260 feet, and rose nearly to the surface. The old town of Hastings is built on the Ashdown Sands. It consists of an upper rock bed, and sandstones separated by shales. The top beds form the base-rocks of Hastings and Ecclesbourne

Wadhurst Clay consists of shale and clay, with alternations of Calciferous Grit (Tilgate Stone of Dr. Mantell) and clay-ironstone, the latter especially occurring a few feet above the Ashdown Sand, and formed the chief source of the iron

of the Wealden Ironworks. Wells at the Brewery, Battle, Ashburnham Place, and Eason's Green, about 60 feet in those clays, probably derive their water from the Ashdown Sands.

My colleague, Mr. Topley, has very ably pointed out the relation of the parish boundaries* of the South-east of England to the great geological escarpments, due in chief measure to the early settlement of these regions by our ancestors on districts affording a water supply.

The villages invariably stand at the foot of the Chalk escarpment here, as in Yorkshire; where the Upper Greensand is present they stand upon it; if absent on the basement beds of the Chalk, which form good arable soil, and throw out springs supported by the Gault beneath; the *parishes* invariably ascend the escarpment and extend to the crest, and but rarely descend the slope. This is true of the whole Chalk region of England, the long diameter of the area of the parish corresponding to the dip of the beds. This I have found to be also the case in the Vale of Eden, where the villages occur on the Permian sandstone, and the parishes extend up the mountain limestone escarpment thrown up by the Pennine fault.

South of the Weald there are no less than 35 villages on the Upper Greensand in Sussex, and 13 in Hampshire, while on the Gault there is only one in Sussex, and none in Hants; no less than 119 parishes ascending the Chalk escarpment, their villages lying below it.

The *Lower Greensand* is reduced in East Sussex to 60 or 70 feet. The Gault in East Sussex averages 100 feet. It is overlaid by 40 feet of *Upper Greensand* at Eastbourne, passing upwards into Chalk with green grains.

Battle.—*Acres*, 8076; population, 3319; from two contiguous wells; pumped up to reservoir; the water is turned on three times a week, about 10,000 gallons each time, to the town only; some of the houses do not require a supply; rateable value, 8202*l.*

Hastings (Sussex).—*Acres*, 1821; population, 29,291 in

* 'Journal of the Royal Agricultural Society.'

1871, 42,256 in 1881; from 44 wells and 4 ordinary wells pumped into service reservoir for high levels; the greater part of the water supplied to low levels is filtered; about 600,000 gallons, intermittent; rateable value, 224,806*l.* 10*s.*; the Local Government Board and Public Health Acts.

Eastbourne (Sussex).—*Acres*, 4755; population, 10,400 in 1871, 21,977 in 1881; from a private Company; artesian well; rateable value, 80,000*l.*

Lindfield.—Population, urban district, in 1881, 866; wells only; rateable value, 2414*l.* 5*s.*

St. Wilfred's.—*Acres*, 920; population, 1276 in 1871; wells only; rateable value, 6798*l.*

RIVER CUCKMAR (CLXXVIII.).

Length, 17 miles; area, 75 square miles; of which 17 consist of the Chalk Downs, 10 of Greensand and Gault at their northern foot, 15 of Weald Clay, and 33 of Tunbridge Wells Sand. Villages, Hailsham, Chiddingly, Seaford.

Weald Clay reaches its maximum development at Leith Hill, thinning eastward. Between Tunbridge and Maidstone it is about 600 feet; under Hythe it is estimated by Mr. Topley at probably 350 feet; in the Lower Boulonnais it has disappeared altogether. In the Itchingfield and West Grinstead district, 120 feet above the base of the clays, occurs the "Horsham Stone." This grit is occasionally quarried. Over it are successive horizons of *Paludina* limestones, known as "Sussex Marble."

RIVER OUSE (CLXXVII.).

Length, 28 miles; area, 208 square miles, of which only 27 miles occupied by Chalk are south of the Weald. Of the district north of the Downs, Greensand and Gault occupy 12 miles, Weald Clay 12 miles, and Tunbridge Wells Sand 154 miles, on which are the towns of Cuckfield and Uckfield. Lewes is on the Chalk, with a rainfall of 33·5. The river has here cut a gorge to the sea through higher and higher beds of the Chalk at the point where the river falls

into the sea. The valley is broad, and occupied by an alluvial flat, in which is Newhaven Harbour.

Uckfield (Sussex).—*Acres*, 1760; population, 2146; private wells and spings; rateable value, 6481*l.*

Mean annual rainfall at Uckfield Observatory, 149 feet above Ordnance Datum :—

1850–9.	1860–9.	1870–9.	1880.
30·03	31·24	31·02	30·76

Cuckfield.—*Acres*, 207; population, 1713; wells only; rateable value, 3464*l.*

Lewes (Sussex).—Population, 6017; supplied by the *Lewes Waterworks Company;* from wells upon their own premises.

Mean annual rainfall at Glynde Place, 45 feet above the sea :—

1860–9.	1870–9.	1880.
33·65	33·75	29·49

St. Thomas-in-the-Cliffe. — *Acres*, 35; population, 1664; private wells and public pump of spring water, also by *Lewes Waterworks Company;* rateable value, 5635*l.* 15*s.*

ORDNANCE SURVEY CATCHMENT BASIN CLXXVI.

Area, 56 square miles, entirely on the Chalk.

Its northern watershed traverses the top of the Chalk escarpment, the water falling on the northern slope of the Downs flowing into the Weald, into ground drained by a tributary of the *ADUR.*

Between Newhaven Fort, Rottingdean, and Kemp Town the Chalk forms a line of steep cliffs, but westward from Black Rock the cliffs trend inland, and are masked by drift deposits, consisting of a subaerial loam, with elephant remains, resting on an ancient raised beach.

Brighton (Sussex).—*Acres*, 2592; population 107,528; pumped from wells and tunnels bored in the Chalk. Seven reservoirs, the total storage capacity of which is 6,300,000 gallons. There are two distinct series of works,

one on the east and one on the west side of the district; each consists of a pumping station, and of three zones of supply mains and pipes, fed from three reservoirs at different levels. These reservoirs are connected by the service mains in each zone, so as to make use of the pressure to the fullest extent. There is also a fourth service on the eastern side of the town, for the supply of the workhouse, race-stand, and other higher parts of the district. The average quantity used daily is about 3,000,000 gallons (C. and I.) Rateable value, Brighton Sanitary District, 554,224*l.*; outside Sanitary District, estimated at 170,000*l.* The works were purchased by the Corporation from a Company under the powers of the Brighton Corporation Waterworks Act, 1872. The Corporation are contemplating the expenditure of 10,000*l.* or 12,000*l.* in increasing the size of some of their mains.

The Lewes Road well is 100 feet deep, and the water rises to within 25 feet of the surface. The well at Goldstone Bottom is 160 feet deep, and 10 large fissures open into it; one is said to deliver 500 gallons a minute. Both are clear, brilliant, and palatable, but would be improved by Clark's process. All the good qualities of these waters, with the addition of softness, are also found in the wells supplying the workhouse and its schools, reaching a depth of 1285 feet; the supply is, however, not sufficient, owing to an accident to the borehole. It penetrates the Chalk and Gault, the latter being a pale-grey marl.

Rivers Pollution Commission Analyses.

Locality.	Well in Feet.	Temp. Cent.	Total Solid Impurity.	Chlorine.	Hardness.			Remarks.
					Perm.	Temp.	Total.	
Workhouse School	1285	9·9	35·36	8·40	1·2	3·2	4·4	Clear and palatable.
Goldstone Bottom	160	9·6	30·24	3·10	6·4	14·8	21·2	„
Lewes Road ..	100	10·0	32·40	3·70	6·9	14·6	21·5	„

The water in the first analysis is from the Lower Greensand; the wells in Goldstone Bottom and Lewes Road are in the Chalk.

Rainfall at 206 feet above Ordnance Datum.

1876.	1877.	1878.	1879.	1880.
31·87	34·91	29·79	30·98	28·89

Sea water taken from the end of the New Pier had a total solid impurity of 3835·2, of chlorine 1962·5, and a hardness of 673·5, of which only 7·5 was temporary, in parts per 100,000.

Hove (Sussex).—*Acres*, 775; population, 11,221 in 1871, 20,789 in 1881; from waterworks now the property of the Brighton Corporation, and formerly owned by a Company; rateable value, 152,307*l.* 16*s.* 9*d.*

RIVER ADUR (CLXXV.).

Length, 16 miles; area, 160 square miles, of which nearly all is within the Weald, consisting of Tunbridge Wells Sand 18 miles, Weald Clay 77, Greensands 47. Of the 27 miles of Chalk part forms the northern faces of the Downs, draining into the Brighton and Worthing Basins, and part is the gorge through which the river drains to the sea, which it reaches at New Shoreham. Inland it drains Bramber, Steyning, and Hurstpierpoint. Rainfall, 31·1 inches.

New Shoreham (Sussex).—*Acres*, 170; population, 3572; Water Company and private wells; natural spring, from hills pumped into reservoir (c.); rateable value, 9078*l.*; Shoreham Waterworks Act.

RIVER ARUN (CLXXIII.).

Length, 37 miles; area, 160 square miles, of which 24 are Tunbridge Wells Sand, 136 Weald Clay, 138 Greensands and Gault, 63 Chalk, and 9 Tertiary. Its northern watershed extends for a considerable distance from east to west, following the crest of the high ground forming the Wealden anticlinal, separating its waters from those of the *Mole* and the *Wey* flowing into the *THAMES*. South of

Dorking the watershed attains an elevation of 965 feet, and above Haslemere of 894 feet; between these points a col in the watershed, through which a canal is carried at 163 feet above the sea, connects the navigable portion of the *Wey* near Guildford, falling in at 129 feet, and the navigable portion of the *ARUN*, a few miles north of the point where the river receives its tributary, the *Rother*. With the exception of the extreme northern end of the canal in the *THAMES* Valley, the whole of it is constructed on the Weald Clay, and it is the only canal crossing the anticlinal watershed, which is, however, penetrated by six lines of railway, which get through it by tunnelling.

The tributary *Rother* is 23 miles long, rises near Selborne, and flows past Petersfield and Midhurst, up to which point the river is navigable; Petworth, chiefly over the Greensand, falling into the *ARUN* at Hardham.

Horsham (Sussex).—*Acres*, 785; population, 5720; subsoil spring; well, reservoir, and stand-pipes; from 50,000 to 60,000 gallons (constant); rateable value, 17,528*l.*; works purchased by the Urban Sanitary Authority from the *Horsham Waterworks Company*, under the Public Health Act, 1875; a water tower is about to be erected.

Arundel.—*Acres*, 1968; population, 2748; from wells and a natural spring called the Mill Stream; reservoir and mains (constant); rateable value, 9169*l.* 10*s.*; the water supply tank and mains were put down by the Duke of Norfolk, and presented to the town; but there is no supply to individual houses. Mean annual rainfall * at Dale Park, 316 feet above the mean sea-level:—

1860–9.	1870–9.
33·73	33·81

Littlehampton.—*Acres*, 1222; population, 3894; no system of water supply at present exists in this district. The Local Board have had a boring made to the depth of

* Symons's 'British Rainfall, 1880.'

nearly 500 feet, and it is hoped that good water in sufficient quantity for the requirements of the district will shortly be obtained from this source. The inhabitants now supply themselves from surface wells. The whole district between Worthing and Portsmouth is described by Mr. Shelford, C.E.,* "as alive with artesian springs," and especially refers to an important spring near Littlehampton.

O.S. CATCHMENT BASIN CLXXIV.

These streams occupy 35 square miles, of which 30 are Chalk and the remainder Tertiary deposits; they drain a tract of Chalk country, which, when the coast-line stood further out to sea, must have flowed into the rivers *ADUR* and *ARUN* respectively, but which now, through the destruction of the coast-line, discharge directly into the sea.

West Worthing.—*Acres*, 500; population, 688; well sunk into the Chalk; there is no reservoir; 4000 to 6000 gallons (intermittent); rateable value, 5474*l.*

Worthing (Sussex).—*Acres*, 979; population, 10,976; Chalk; two wells, one 360 feet deep, the second 400 feet deep, headings required to increase supply; 330,000 gallons (constant); rateable value, 40,809*l.*; Public Health Act; headings to increase the supply are needed, so as to afford the supply in 10 hours' working.

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* 'Min. Proc. Inst. Civil Engineers,' vol. xlvii., 1877.

CHAPTER XVI.

HAMPSHIRE BASIN GROUP OF STREAMS.

THE area drained by the 18 basins making up this natural group is bounded by a watershed extending 220 miles, of which the greater portion follows the outcrop of the Greensands and the basement beds of the Chalk. Commencing on the Chalk Downs between Arundel and Petworth, it trends by Selborne and Alton to the Basingstoke and Vale of Pewsey anticlinal axis, thence it fringes the northern limit of Salisbury Plain, passes on the Greensand between Warminster and Wincanton, and crosses the Oolites for 22 miles; it again reaches the Upper Greensand forming the top of the North Downs at Cerne Abbas, when it turns abruptly eastwards at a very acute angle, forming the southern limit of Trough of Poole, and, following the Purbeck axis of elevation, reaches the sea, and reappears on the crest of the axis of elevation traversing the Isle of Wight from the Needles to the Whitecliff Bay.

That portion of the island lying south of this watershed must be regarded as a portion of land, since destroyed, once continuous with the Isle of Purbeck and the Dorchester country. When the country stood higher, and before lands now covered by the English Channel were destroyed, a large river probably flowed east through the Solent and past Spithead, receiving the drainage of these streams. Before the *ARUN*, the *ADUR*, and the *OUSE* had cut for themselves a channel through the South Downs, the drainage of the southern slopes must have made its way to the old river, and its watershed followed the basement of the Chalk from the present termination near Arundel to Beachy Head. The existing watershed is now formed by a line traversing the Chalk for 10 miles from its lower to its higher beds, running from the South Downs to the sea at Bognor, and

separating the waters of the *ARUN* from those flowing into the Pagham Estuary.

STREAMS: O.S. CATCHMENT BASIN CLXXII.

Area, 26 square miles, half of which consist of Tertiary deposits and half of Chalk; the coast around BOGNOR is on the Tertiary. The Local Sanitary Authority of this town includes a district with 3289 inhabitants. Its rateable value is 10,797*l.* It is supplied with ordinary wells.

O.S. CATCHMENT BASIN CLXXI.

These streams drain 235 square miles, of which 141 are Chalk and 94 Tertiary. From Selsey Bill to Gosport the coast-line is deeply indented, and several tracts form islands at high tide.

CHICHESTER.—*Acres*, 1827; population, 8092; private wells, and artesian well * in chalk pumped into reservoirs of Waterworks Company; 60,000 gallons, with constant supply; rateable value, 27,281*l.*; Chichester Waterworks Act, 1873, 36 & 37 Vict. c. 29. Mean annual rainfall at Westgate, 40 feet above Ordnance Datum:—

1850–9.	1860–9.	1870–9.
32·23	33·22	35·03

PORTSEA.—*Acres*, 216; population, 17,079.

PORTSMOUTH.—*Acres*, 4485; population, 127,953; springs at Bedhampton near Havant, pumped into reservoirs at Portsdown Hill, descend by gravitation; constant; rateable value, 350,407*l.*; Portsmouth Waterworks Company's Act.

There are numerous brewery wells at Portsmouth. One of the deepest is that in Penny Street, 366 feet, yielding 158,112 gallons in 12 hours. Wells at Gosport, Blockhouse Fort, and Long's Brewery, Southsea, are all about 300 feet deep. The Royal Dockyard well is 1034 feet deep, and yields $2\frac{3}{5}$ tons of water per hour. The surface of the Chalk was reached at 410 feet, and it was bored into for 630 feet without penetrating it. Over the Chalk were 114 feet of mottled

* Mr. Shelford, C.E., states this well overflows.

clays. The *Gosport Waterworks* well is 327 feet, and was sunk through shelly sands and clays. Water was reached at 151 feet.*

HAVANT.—*Acres*, 3150; population, 3027; intermittent supply from mains of *Portsmouth Waterworks;* by Provisional Order.

FAREHAM.—*Acres*, 6525; population, 7171; wells in chalk and reservoir; supply 250,000 gallons, constant; rateable value, 28,837*l.*; Public Health Act, 1848, and Local Government Act, 1858.

ALVERSTOKE.—*Acres*, 4985; population, 21,571; *Gosport Waterworks Company;* artesian well; rateable value, 46,894*l.*; 21 & 22 Vict., May, 1858.

The following thicknesses, taken from Sheet 74 of the Horizontal Sections of the Geological Survey by Mr. Bristow, F.R.S., elucidate the structure of this district:—

	The Solent at Gosport. Feet.		Fareham Common. Feet.
Bracklesham Beds	150	=	40
Lower Bagshot Sands	20	=	20
London Clay	270	=	90
Reading Beds	120	=	60
Chalk with flints	(+)	=	(+)
	570		210

An anticlinal roll brings in the Chalk at the County Lunatic Asylum, south of the River *Titchfield*, for a short distance, where the Tertiaries, which continue to Bishop Waltham, thin out at the Wheatsheaf Inn, where the Chalk attains a thickness of 860 feet between the base of the Tertiary and the top of the Upper Greensand.

O.S. CATCHMENT BASIN CLXV.

These streams occupy 85 square miles, of which 1 is occupied by Greensands and Gault, 66 by Chalk, and 18 by Tertiary deposits. Villages, Seberton, Droxford, West Meon.

* The wells in the Sea Forts, at No Man's Land, and the Horse Fort, are carried through the Bracklesham beds, to a depth of 570 feet below high-water mark.

RIVER HAMBLE (*CLXIV.*).

Length, 6 miles; area, 35 square miles; the whole of which are Tertiary deposits.

RIVER ITCHIN (*CLXIII.*).

Length, 26 miles; area, 231 square miles, of which 143 are Chalk, and 38 Tertiary deposits. The watershed west of Alton attains an elevation of 702 feet, and west of Basingstoke of 586 feet, above the sea.

A roll in the Chalk comes in between the River *HAMBLE* and Gonder Down, where the Chalk is represented by Mr. Bristow, F.R.S.,* as 800 feet thick, the upper half being the Chalk with flints, the lower 400 feet or chalk without flints having its base under the River *ITCHIN*, 300 feet beneath the mean sea-level.

Under Itchin Down, Micheldever Wood, and Stratton Park the base of the Chalk is about 400 feet below the sea-level; from the last locality it commences to rise steadily northward; at Popham Beacon it is only 250 feet below the sea-level and 780 feet beneath the surface; its continued upward trend will be described in the *TEST* Valley.

Alresford.—*Acres* (registration sub-district), 18,731; population, 3561.

Winchester.—Population, 17,469; well of Waterworks Company; supply intermittent; rateable value, 60,657*l.*; private Act.

Southampton.—*Acres*, 2817; population, 60,325. Flows by gravitation from the River *ITCHIN* into impounding reservoir, thence into pump wells, from which the water is pumped to reservoirs on Southampton Common, from whence it flows by gravitation. The water is filtered, and a constant supply of 3,500,000 gallons is given;† rateable value,

* Horizontal Section, Sheet 74, of the 'Geological Survey of England and Wales.'

† A boring passed through 80 feet of Gravel, 300 feet of London Clay, 100 feet of Mottled Clay, and 40 feet of Chalk, water stood at 38 feet from the surface.

214,898*l.*; Southampton Waterworks Act, 1836; Amendment Act, 1850; Public Health Act, 1875.

RIVER TEST or RIVER ANTON (*CLX.*).

Length, 26 miles; area 477 square miles, of which 407 are occupied by Chalk, and 70 by Tertiaries. Chief places, Fawley, Romsey, 81 feet, Stockbridge, 120 feet, Andover, and Whitchurch, which is just under the Chalk Down forming the watershed between this river and the *THAMES* Basin. A canal is carried parallel from Andover, at 185 feet, to the point at which the river falls into Southampton Water, which extends for 10 miles southwards, and receives on their northern banks the waters of the *ITCHIN* and the *HAMBLE*.

Romsey.—Population, 4204; wells, pumps, and river; the mains of the *South Hants Water Company* are laid throughout the borough, but the water *is not* taken.

Shirley.—*Acres*, 1496; population, 7142; wells; arrangements pending to take water from *South Hants Waterworks Company;* rateable value, 11,310*l.*

Andover.—*Acres*, 7670; population, 5654; partly by wells and partly by *Andover Waterworks Company* (Limited); reservoir; rateable value, 22,000*l.*

The base of the Chalk under the river *TEST*, near Overton (London and South-Western) Station, is 130 feet beneath the sea-level, and 400 below the surface, the greater part of the Chalk with flints being denuded away. At the Roman Road, north of Poolhampton, the base of the Chalk is above the sea-level, the Upper Greensand is represented as 200 feet thick, and the Gault as 180 feet (Geol. Survey, Horizontal Section, Sheet 74, Mr. Bristow, F.R.S.).

RIVER BEAULIEU (*CLXII.*).

Length, 8 miles; area, 52 square miles, of which the whole consists of Tertiary Deposits; villages, Exbury and Beaulieu; averarge rainfall, 30·2.

RIVER LYMINGTON (CLXI.).

Length, 8 miles; area, 91 square miles, the whole of which is occupied by Tertiaries. The New Forest occupies the centre of the Bagshot Sand tract, extending over this basin, and that of the Beaulieu. Rainfall, 30·8. Chief places, Brockenhurst and Lyndhurst.

Lymington.—*Acres*, 2257; population, 4360; well, 40 feet deep, gives moderate supply; rateable value, 14,842*l.*; town 34 feet above sea.

RIVER AVON (CLIX.).

Length, 61 miles; area, with tributaries, 673 square miles, of which 18 consist of Oolites, 63 of Greensand and Gault, 509 of Chalk, and 83 of Tertiaries, chiefly Bagshots.

This basin occupies a fan-shaped area; the Chalk of Salisbury Plain and the Greensand of the Vale of Pewsey form the extended portion of the fan, the Tertiaries between Fordingbridge and the sea at Christchurch the handle. Its northern limit runs along the crest of Roundway Down, above Devizes, at the western temination of which the three watersheds meet, separating the south coast of East *AVON* from the Lower or West *AVON*, flowing into the Bristol Channel, and from the *Kennet* forming part of the *THAMES* Basin.

The *AVON* is navigable up to Salisbury, where it receives three tributary streams. On the right bank is the *Bourne*, rising, like the *AVON*, in the Greensands of the Vale of Pewsey; on the left bank is the *Wiley*, 24 miles long, rising in the Greensands of Warminster; and a third stream rising in the Greensands of Shaftesbury. The rainfall of the *Wiley* is 29·1.

The canal connecting the Bristol *AVON* at Devizes with the *Kennet* at Hungerford crosses the northern end of the *AVON* watershed; it crosses the Bristol *AVON* watershed at 430 feet, and passes across the *THAMES* watershed at 413; descending in that line to 318 feet at Hungerford; thence following the side of the *Kennet* to Reading.

WARMINSTER.—*Acres*, 6481; population, 5640; private wells, and pipes from stream distributed over Warminster Common; rateable value, 21,061*l.*

SALISBURY.—*Acres*, 599; population, 14,576; well and boring in chalk, pumped into reservoir, 650,000 gallons; intermittent; rateable value, 45,073*l.*; Public Health Act, 1848.

WILTON.—*Acres*, 1700; population, 1826; from a well sunk in gravel at foot of Groady Hill, near Wilton, pumped into reservoir; gives intermittent supply; rateable value, 2810*l.*; Public Health Act, 1848.

RIVER STOUR (CLVIII.).

Length, 54 miles; area, with its tributaries, 459 square miles; 120 are occupied by Oolites, 19 by Greensands, 249 by Chalk, and 71 by Tertiaries, much of which are permeable; so that the whole basin is occupied by porous rocks, absorbing a large amount of the rainfall.

The *STOUR*, like the *AVON*, drains a fan-shaped area, the margin in this case consisting of Oolitic rocks, which are traversed in the direction of their strikes by the watershed of the *PARRET*, flowing into the Bristol Channel at Bridgwater. From Stalbridge the *STOUR* flows down the dip of the Oolitic rocks over higher and higher beds, until it reaches the Cretaceous escarpment called the North Downs, which it breaches at Blandford, precisely in the same manner as the *THAMES*, flowing across the Oolites of the Oxford Plain, breaches the Chalk escarpment above Henley.

The area occupied by Oolitic strata west of the diagonal watershed occurring between Crewkerne and Cheltenham is 768 square miles. The rainfall thrown off in floods and surface drainage of the area flows into the *SEVERN* and Bristol Channel streams, but the amount absorbed by the permeable portion of the Oolites flows down the dip planes of the strata, and passes beneath the Cretaceous rocks of the Hampshire and *THAMES* Basin, or at least that portion of the latter lying south of the *THAMES*.

The areas of Oolitic rocks in the basins west of the diagonal watershed are:—

Flowing underground into the Thames Basin.	Square Miles.
Severn	94
Bristol Avon ..	340
	434

Flowing underground into Hants Basin.	Square Miles.
Parret	62
Brue and Axe ..	52
Avon	220
	334

Which, assuming an average daily percolation of 10 inches, or 400,000 gallons, per square mile, would give a daily volume of 130,000,000 gallons of underground water flowing under the Cretaceous rocks of the *Kennet* Valley, and 100,000,000 gallons flowing under the Cretaceous rocks of Salisbury Plain, a quantity sufficient, if all yielded up to borings, at 30 gallons per head, to provide a water-supply for 4,250,000, and for 3,000,000 persons respectively.

North of the *THAMES*, the underground drainage of the Oolites, flowing beneath the Cretaceous rocks, is received east of the diagonal watershed, and within the *THAMES* Basin, but as these rocks are not present in the deep borings near London, and thin out steadily eastwards, they cannot be considered available for water-supply purposes in the country lying east of Reading.

Shaftesbury (Dorset).—Population, 2312; supplied by Waterworks belonging to the late Duchess of Westminster; rateable value, 4722*l.*

Blandford Forum (on the Chalk).—Population, 3753; rateable value, 8824*l.*

Sherborne.—*Acres*, 411; population, 5053; deep well and reservoir; 240,000 gallons; constant; rateable value, 13,037*l.* 0*s.* 4*d.*; Public Health Act.

Wincanton and Stalbridge, on the Oolite; Sturminster Newton, up to which the river is navigable, on the Greensand; Wimborne Minster, on the Tertiaries, 75 feet above the sea. Rainfall, 31·1.

The *Cole*, 11 miles long, and several other feeders, rise in

the Oolite country, and fall into the main stream above Sturminster Newton. The rainfall of this area is 28·2.

RIVER TRENT (*CLVII.*).

Length, 21 miles; area, 119 square miles, of which 50 consist of Chalk, and 69 of Tertiaries. This basin has only an average width of 4 miles. Its western limit is the crest of the Chalk Downs above Cerne Abbas; it does not extend into the Greensand or Oolite country beyond the escarpment, but receives underground drainage from both these formations in the *STOUR* Basin, as well as from the Oolite on the west side of the diagonal watershed. Crossing the Tertiaries, the river falls into a broad and deeply-indented estuary, which also receives the water of the *FROME*, which practically forms one basin with the *TRENT*, draining the Trough of Poole.

Bournemouth.—Population, 16,859 in April 1881; ordinary well; reservoir; 250,000 to 300,000 gallons; intermittent; rateable value, 102,251*l.* 2*s.* 6*d.*; Bournemouth Gas and Water Act, 1873, 36 Vict. c. 73.

Poole.—*Acres*, 4749; population, 12,303; private Company; reservoir; rateable value, 30,347*l.*; Poole Waterworks Act, 28 Vict. c. 21, 1859; 11 feet above the sea.

Between the rivers *FROME* and *TRENT* is the town of Wareham, 12 feet above the sea; *acres*, 122; population, 2100; wells and the two rivers; rateable value, 4484*l.*

Dorchester.—*Acres*, 142; population, 7568; Corporation well in chalk, 7 feet shaft; 135 feet deep, with a 60-feet borehole, and a 30-feet borehole, pumped into a service tank holding 300,000 gallons; 440,000 gallons pumped daily; temperature of water, 8°·3 Cent.; total solid impurity, 29·90; hardness, 23·6, of which 5·3 is permanent; rateable value, 14,900*l.*; Public Health Act, 1848.

ISLE OF WIGHT STREAMS.

North of the Central Watershed.

The geological structure of the Isle of Wight is remarkable for the large number of formations occurring within its

144 square miles of area. From the interesting character of its sections and the beauty of its scenery, perhaps no part of the country has been described more often, or in more detail.

In the disposition of its strata, and in the influence of the east and west axis of elevation traversing the island, it may be compared to the North Downs, especially that part forming the Hog's Back near Guildford, where the steepness of the dip of the Chalk and underlying Greensand and Gault cause the outcrop to be exceedingly narrow. The Downs also are breached by the *Wey*, flowing north from a Lower Greensand country, as the *Wey* traverses the Tertiaries at the base of the Hog's Back on its way to the *THAMES*, precisely in the same manner as the *MEDINA*, after draining the Lower Greensand area of the south of the Isle of Wight, flows due north through the Chalk escarpment, traverses the Tertiaries, and falls into the Solent. The Isle of Wight Chalk escarpment is also breached by the *BRADING* flowing north-east, or somewhat obliquely to the dip, much after the fashion that the *MEDWAY* breaches the North Downs, between Maidstone and Rochester.

As already stated, the Isle of Wight Chalk Downs were once prolonged westwards to the Chalk Downs of the Isle of Purbeck, the Needles still attesting to their former extension, and exhibiting fragments of their shattered and destroyed hills. In the Isle of Purbeck the Downs have been nowhere breached by streams flowing through them, and the watershed traverses the crest of the Chalk.

Streams North of the Central Watershed.

O.S. Catchment basin clxvi.	11	
„ „ clxvii.	25	
River Medina (clxviii.)	28	Newport.
O.S. Catchment basin clxix.	19	Ryde.
Brading Stream (Part of clxx.) ..	27	Brading.
	110	square miles.

In this area occur of Tertiary deposits 60 square miles, of Chalk 12, of Greensands and Gault 38, nearly the whole of which are permeable.

The surface of the Chalk beneath the Plastic Clay is eroded and uneven, a slight unconformability occurring between the two. The upper beds are hard and compact, traversed by beds of large black flints, which throw off a line of springs along the outcrop. At Whitecliff Bay, between red mottled Plastic Clay and the iron-stained sandy London Clay, is a band of scattered pebbles, representing the basement bed of the London Clay of Professor Prestwich. The Plastic Clay at Alum Bay is stated by the Geological Survey to be 84 feet thick, and 163 feet at Whitecliff Bay, thickening from west to east 79 feet in 22 miles, or $3\frac{1}{2}$ feet per mile. The London Clay also thickens eastwards from 199 feet 8 inches at Alum Bay to 295 feet at Whitecliff Bay, 95 feet 4 inches in 22 miles, or $4\frac{1}{3}$ feet per mile.

The Middle Eocene series consists in descending order of the—

Barton Series—Brown Clays	300 feet.
Bracklesham Series—Brown Clays, Greensands, Variegated Sands	111 „
Lower Bagshot Sands—Unfossiliferous Sands	661 „

Professor Judd estimates that the *Barton Clay* contains not less than 1000 forms of marine life. It is represented in the Paris Basin by the "Sables Moyennes," or "Sables de Beauchamp," and in Belgium by the "Système Laekénien" of Dumont, and forms the uppermost member of the Eocene or Nummulitic formation.

Lying above the Barton Clay is the *Headon Series*, estuarine strata, freshwater limestones, clays, lignites, and sands, attaining a thickness of 400 feet, overlaid by marine beds containing a marine fauna, which Professor Judd has called the Brockenhurst Series, and which he groups with the Headon Series, as the Lower Oligocene. At Whitecliff Bay they attain, according to Professor Judd, 100 feet, at Colwell Bay 25 feet only, while their thickness in the New Forest is doubtful.

The *Headon Hill Sands* overlying the Barton Clay, Professor Judd believes, are not to be referred to the Upper Bagshots, but, though unfossiliferous at Alum Bay, contain the characteristic shell of the Headon series, *Cerithium concavum*, at Hordwell Cliff.

Above the *Brockenhurst Series* occurs the Bembridge Series of the Geological Survey, consisting of 130 feet of Upper Marls, Bembridge Limestones (freshwater) 25 feet, and 100 feet of Lower Marls at the western end of the island. At the eastern end of the island, between Ryde and St. Helens, these lower beds alter their character, and pass into sands and conglomerates, forming the St. Helens Sands, resting on the Nettlestone Grits of Professor Forbes.

Five feet above the Bembridge Limestones is a band in which marine shells are associated with freshwater forms; only 80 feet of the overlying Upper Marls occur at the east end of the island. The 130 feet at the west end include, according to Professor Judd, beds formerly considered as the lower beds of the Hampstead Series, which, thus limited, only reach 100 feet. This marine horizon has not been identified on the Hampshire shore, and is the equivalent of the lower part of the Middle Oligocene of the Continent, and there is no means of determining whether the upper part, or the Upper Oligocene, was even present in the Hampshire Basin, but the beds occurring there attain a thickness of 900 feet.

Professor Judd's researches lead to grouping the Lower and Middle Headon of Professor Forbes and the Headon Sands into one series, and to absorb into the overlying Bembridge group the Upper Headon Beds and Osborne and St. Helens Series * of Professor Forbes; but Professor Judd's views have since been criticized by Mr. Tawney, who supports the original identification of the Geological Survey.

East Cowes.—*Acres*, 516; population, 2615; rainfall collected by catchwaters stored in reservoir, 9000 gallons

* The St. Helens Fort well penetrates 19 feet of concrete, 74 feet of drift, 2 of peat, and 17 feet of Bembridge beds, &c. The water rises to the level of mean tide. This was the first well constructed in the Portsmouth Channel, by the advice of Mr. R. W. Mylne, C.E., F.R.S.

a day, but only supplies two-thirds of district; rateable value, 8031*l.*; Public Health Act, 1848 and 1858.

Newport (Isle of Wight).—*Acres*, 501; population, 9430 (previous to passing Newport Borough Act, 1876, enlarging boundary, was 6782); springs above the village of Carisbrooke in the chalk yield 100,000 gallons, conveyed to a covered reservoir; a well near the springs yields 150,000 gallons, pumped into another reservoir, 180 feet above Ordnance Datum. The Rivers Pollution Commission gives the temperature of these springs at 8°·6 Cent.; total solid impurity, 28·50; chlorine, 3·30; hardness, 29·4, of which 6·0 is permanent. The Carisbrooke Castle well in chalk, 240 feet, was distinctly polluted; temperature, 11°·3; total solid impurity, 43·28. Rainfall in 1879, at 57 feet above Ordnance Datum, 37·4 inches.

West Cowes.—*Acres*, 1000; population, 6487; catchwaters in sand and gravel, collected in four open reservoirs, holding 16,000,000 gallons; 125,000 gallons intermittent; rateable value, 20,189*l.*

Ryde.—*Acres*, 762; population, 11,422; springs collected in small reservoirs, pumped daily into service reservoir, average supply 200,000, maximum supply 1,000,000 gallons; rateable value 73,533*l.* Ryde Improvement Act, 1854, and Ryde Corporation Water Act, 1861, gives power to supply 1 mile beyond their boundary. Rainfall in 1879, 34·41 inches. The water from the springs near Ryde has a temperature (Rivers Pollution Commission) of 5°·8; total solid impurity, 27·62; chlorine, 2·70; hardness, 20·6, of which 7·1 is permanent.

St. Helens.—Population 4210; western district supplied by Ryde.

Sea View Village supplied only by rainwater tanks.

Osborne.—At Osborne, No. 5 Trial Well gave water of only 7·7 degrees of hardness, the whole of which are permanent; chlorine, 3·0; and a total solid impurity of only 13·08. Mean annual rainfall, at 172 feet above the sea:—

1860–9.	1870–9.
30·73	29·21

Isle of Wight Streams: South of the Central Watershed.

STREAMS: O.S. CATCHMENT BASIN CLXX. (in part).

The elevated hilly ground of the south of the Isle of Wight consists of permeable Cretaceous rocks, which do not give rise to a river of any size. Near the coast numerous small streams cut a V-shaped gorge through the cliffs, forming the picturesque "Chines," one of the characteristic features of the island.

The area drained by these Chines is 24 square miles, of which Weald Clay occupies 4 square miles, Greensands and Gault 11, Chalk 6, Tertiaries 3. The Weald Clay, being impermeable, will support the water in the Lower Greensands, which are well seen at Shanklin, where they were long ago described by Dr. Mantell; but, from the large quantity of iron occurring in these rocks, the quality is probably not good. The Gault, locally called "blue slipper," is above 100 feet thick, and plays an important part in the scenery of the island, from its constant tendency to cause landslips; these and the lines of springs thrown out at the base of the Upper Greensand have been the cause of the formation of the Undercliff at Ventnor. Between Sandown and Whitecliff the Gault is about 50 feet thick, and is fossiliferous. In the Isle of Wight it is often sandy and slightly micaceous.

Sandown.—Population, 3107; pumped from River *YAR* by a private Company. The *YAR* is just beyond the watershed of the basin in which the town is situated. Supply constant; rateable value, 15,876*l.*; private Act, 24 Vict. c. 55.

Shanklin.—*Acres*, 650; population, 2764 in the winter, 4500 in the summer; supply intermittent from wells and headings in the Upper Greensand, yield 70,000 gallons a day, stored in service reservoirs holding 100,000; rateable value, 13,600*l.*; Public Health Act, 1858 and 1875.

Ventnor.—*Acres*, 1000; population, 5493; springs collected by *Ventnor Gas and Water Company;* supply intermittent; rateable value, 25,542*l.*

The following analyses are given by the Rivers Pollution Commission:—

Wells and Springs.	Temp. Cent.	Total Solid Impurity.	Chlorine.	Hardness.			Remarks.
				Temp.	Perm.	Total.	
	°						
Spring Hill Well	11·5	29·48	4·15	16·7	5·1	21·8	Clear.
Ventnor Waterworks, well near Railway Station ..	10·5	34·72	3·10	21·7	4·6	26·3	„
Wishing Well, Great Boniface Down	10·8	26·40	6·40	6·8	5·6	12·4	„

Rainfall at the Consumption Hospital, Ventnor, 150 feet above Ordnance Datum.

1876.	1877.	1878.	1879.
32·27	35·25	32·41	34·38

Population of the South-coast Rivers; rising south of the Wealden and King's Clere and Vale of Pewsey anticlinals.

Counties.	Population.	Density, Acres to Persons.	Proportion of Population, probably living in this group.	Population, about.
Census of 1871.				
Sussex	417,407	2·2	$\frac{6}{7}$	357,777
Hants	543,837	1·9	$\frac{4}{5}$	435,069
Wilts	257,202	3·4	$\frac{1}{2}$	128,601
Dorset	195,544	3·2	$\frac{4}{5}$	156,455
Census of 1881.				
Sussex	490,316	1·9	$\frac{6}{7}$	420,271
Hants	593,487	1·7	$\frac{4}{5}$	474,790
Wilts	258,967	3·2	$\frac{1}{2}$	129,483
Dorset	190,979	3·2	$\frac{4}{5}$	152,784

CHAPTER XVII.

WEST OF ENGLAND STREAMS.

South-coast Streams south of the Isle of Purbeck Axis.

The diagonal watershed passes from the Lias at Cheltenham, and, crossing the Oolites to the basement beds of the Cretaceous rocks at Swindon, follows the strike of the latter by Warminster to Wincanton, when it crosses a tract of Oolites, again reaching the basement Cretaceous beds in the North Downs of Cerne Abbas, and follows them in their remarkable change of strike from south-west to south-east, from near Crewkerne to the Isle of Purbeck. The Oolitic rocks dip steadily eastward, and the Cretaceous rock rests unconformably on their upturned and denuded edges.

ORDNANCE SURVEY CATCHMENT BASIN CLV.

The district lying south of the watershed between the Chesil Bank and St. Alban's Head occupies 87 square miles, consisting wholly of porous rocks (54 being Oolites, 5 Greensand, and 28 Chalk), giving rise to few streams, and none of large volume.

Between Eggardon Hill and Dorchester the country is composed of a large sheet of Chalk, though the Upper Greensand appears at East Compton and Winterbourne Abbas, being partly brought up by faults. The escarpment of the Chalk, with the Upper Greensand at its base, runs almost continuously from Eggardon, by Askerswell, Long Bredy, Little Bredy, to Abbotsbury Common, where it terminates against a large fault running east, which brings up the Oolites, as shown on the Geological Survey Map, Sheet 17. The fault, however, runs along the higher part of the Chalk escarp-

ment for its greater portion, and the top of the Greensand appears from Bincombe to Poxwell. Southward and westward of this fault the Oolites strike nearly east and west, and the beds are often repeated by "strike faults" running in the same direction, which are evidently of post-Cretaceous age.

In the tract between Abbotsbury and Weymouth Bay the repetition of the beds is due to several west-north-west anticlinal and synclinal rolls, the tops of which appear to have been worn into one uniform plain of marine denudation, sloping from the west-north-west, on the surface of which the Upper Greensand was deposited. Westward from Burton Bradstock the Oolites and Lias dip steadily to the south-east, bringing up higher and higher beds, on the eroded edges of which rests the Upper Greensand, which further inland is surmounted by the Chalk. In addition to the east and west faults traversing the Oolites, there are a great number of faults running about N. 30 E., which cut off the east and west, and are evidently of later date than the former system.

The subsidence in the strata before the deposition of the Cretaceous, pointed out by the anticlinal and synclinal rolls in the Oolitic strata, if commencing at an era when the whole of the West of England stood well *above* the sea-level, would offer exactly the conditions as the curved surface of the ground sunk beneath the waves to produce a plain of marine denudation, which Professor Ramsay has demonstrated must be the invariable result "when a country is gradually sinking, and the rate of waste by the waves on the shore (as it were, slowly entering into the country) be proportionate to the rate of sinking." *

The direction and inclination of such plains of ancient date will have been more or less modified, by curvature caused by subsequent subsidences, and by faults the result of more recent elevations. And even more modern plains may have been locally modified in direction by the strata attacked by

* 'Physical Geology and Geography of Great Britain.' Fourth Edition.

the waves not having been always deposited horizontally, but inclined at small angles around islands of older rock left by still older denudations, or brought up by faults and flexures.

In the South of England, Professor Prestwich, F.R.S., in his address to the Geological Society on resigning the President's chair, describes the great ridge of Palæozoic rocks which is believed to pass beneath the Secondary rocks from the Rhine to South Wales, connecting the old rocks of the Ardennes with those of the Mendips, bringing up Coal Measures in detached basins on its northern flanks, and probably also on the south, as is believed by Mr. Godwin-Austen, who worked out the question in 1856.

In advancing from Lulworth to Lyme Regis, the Lower Cretaceous rocks will be observed to overlap lower and lower Oolitic beds, in consequence of the latter rocks having obtained their anticlinal and synclinal curves, the upward rolls of which were worn into a plain of marine denudation, sloping east-south-east, before the deposition of the Upper Greensand, while both systems of faults traversing the district are of later age than the Chalk.

It would appear that the movement which resulted in the formation of lines of axes in the strata and in its easterly dip was one of subsidence, probably commencing after the Portland Oolite had become a land-surface, through the combined action of deposition filling up the shallow sea-bottom, and of an elevation sufficient to place a considerable portion of the Oolitic sea-bottom above the waves, which area comprised, probably, not only that covered by the Purbecks, but a considerable tract to the west. And that this subsidence, though sufficient to produce the various axes and flexures, and to submerge the area sufficiently for marine forms to exist in Purbeck times, was not of very long duration, or of very great extent, as the freshwater Wealden beds were immediately deposited over the Purbecks.

This axis in the old rocks is an east and west disturbance, causing numerous sharp, narrow anticlinals and synclinals, in Westphalia, Belgium, France, Somerset and

Pembroke, in the curves of which lie very long and narrow troughs of Coal Measures, extending for many miles. Professor Prestwich lays stress on the great thinning out in a southerly direction of the "pre-Cretaceous Secondary rocks" observed by Professor Hull, the Great and Inferior Oolites having thinned from 792 feet in Gloucestershire to 205 feet in Oxfordshire, and the Lias and Trias from 1090 to 400 (?), and the Trias of Lancashire from 5600 to 600 feet in Warwickshire; and he shows that this general southerly thinning out points to old pre-Triassic land, which may well have been the old ridge of Palæozoic rocks running out from the Mendips. There is, therefore, little doubt that the Palæozoic rocks are overlaid uncomformably by successive Triassic, Liassic, and Oolitic beds, precisely as the latter are overlapped by various Cretaceous rocks.

The great east and west axis of disturbance is believed to be of post-Carboniferous or pre-Permian age, which is precisely the era of which Professor Hull writes: "The northern limits of the Lancashire and Yorkshire Coalfields were determined by the upheaval and denudation of the beds along east and west lines, while the Coalfields themselves remained in their original continuity across the region now formed by the Pennine hills from Skipton southwards." *

Sir H. De la Beche regarded the depression that occurred after the deposition of the Wealden beds as of probably small extent, and believed the beds overlying them denoted "comparatively quiet accumulation of sedimentary matter . . . subsequently to the change, as previously," and he remarks on the absence of "coarse detrital beds resting upon the upturned Wealden deposits." And he states that "we are led to suppose that the change may, geologically speaking, have been gradual; and that, subsequently to the gradual rise of a portion of Western Europe, which brought a part at least of the Oolitic series above the sea,

* Professor Hull, 'Relative Ages of Leading Physical Features and Lines of Elevation of the Carboniferous District of Lancashire and Yorkshire,' 'Quart. Journ. Geol. Soc.,' 1868, p. 331.

a gradual depression took place, which permitted the Chalk and Greensand to overspread a wide area, covering up a variety of older rocks. Under this view we should expect the beds forming the lowest portion of the Greensand to be best developed when the depression beneath the sea was first effected, and that consequently the higher beds would be most continuous over the area subsequently occupied by the whole Cretaceous series, due allowances being made (more particularly as to the sands and clays) for variations caused by the operation of modifying conditions in horizontal distances . . . And we might expect . . . that, while the lowest beds of the Greensand were accumulating in the East of England, dry land still existed in the West." *

This depression would appear to have begun in the Yorkshire and Lincolnshire area, where the Lower Neocomian beds are so extensively developed, and probably also under Norfolk, where the base Chalk occurs (Norwich well) at a depth *lower* than the old rocks of Harwich. The line of greatest depression probably extended along an axis ranging from the *HUMBER* across the German Ocean to Hanover; and the subsidence appears to have been more extensive on the southern than on the south-west margin of the basin.

The continental epoch, with large inland seas and lakes, which Professor Ramsay has shown commenced with the Old Red Sandstone era, appears not only to have lasted up to the close of the period occupied by the deposition of Triassic strata, but to have continued, though with a more limited area, during the Liassic and Oolitic periods, when it again gained in area, and was drained by a large continental river, in the delta of which were formed the Purbeck and Wealden beds. A movement of subsidence set in to the east, which gradually extended to the west, introducing marine conditions, the strata of the entire Cretaceous system exhibiting a gradually deepening sea-bottom.

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* 'Report on the Geology of Cornwall, Devon, and West Somerset, 1839.'

The question, Did the continental land wholly disappear beneath the waves at the close of the Wealden era? is an interesting subject for inquiry. The researches of Professor Judd have shown that the Wealden of Germany was deposited by a river distinct from that which formed the deposits of that age in England and France, and that the highest or newest portion present in France is often merely a subordinate horizon to marine beds of Neocomian age; and he points out with great force the truth of Professor Huxley's proposition, that the time will come when two distinct but parallel classifications for dissimilar strata will have to be made, from the breaks in the terrestrial and fluviatile fauna not corresponding to those in the marine. Thus, in the beds of Punfield Cove, Swanage Bay, lying immediately above the Wealden, occurs a fluvio-marine fauna, the marine contents of which Professor Judd has shown are Neocomian, while its fluviatile affinities are with the Wealden. And, again, with the fluvio-marine beds of the Purbecks beneath, the marine affinities are with the Oolites below, while the freshwater and terrestrial are Wealden, as shown by Professor Forbes, who, in 1850, recognized the Neocomian facies of the fine collection of marine fossils made by Mr. Godwin-Austen, F.R.S., at Punfield, and presented to the Geological Society. This "Punfield formation" shows the strongest palæontological affinity to the middle portion of the Middle Neocomian Coalfield of Utrillas,* and other places in Eastern Spain, where three Coal-basins occur, which it is believed will supply "the whole of the peninsula for more than two hundred years."

The researches of M. Lory have shown that the *Rhodanien* of M. Renevier is as closely related to the Upper Neocomian (*Aptien* of D'Orbigny) as it is to the Middle Neocomian (*Urgonien* of D'Orbigny, white limestone with *Rudistes*).

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* The total thickness of the lignite and coal series, consisting of the Upper and Middle Neocomian lying beneath the Gault, is given by Professor Judd at 1600 feet.

This proves, as pointed out by Professor Judd, the arbitrary division of the Upper and Middle Neocomian. And when we see a marine fauna of Upper Middle Neocomian age almost intercalated in the upper part of the Wealden, and the equivalents of a formation occurring in Spain more than 500 feet in thickness associated with large and numerous coal and lignite beds, it is difficult to resist his conclusion, that "as no break has ever been shown to exist in the succession of Wealden beds in the South of England, we are compelled to conclude that they represent the whole of the vast interval between the Upper Oolite and the Upper Neocomian." Between the Purbecks and the Portland Oolite the change is equally gradual, for Mr. Godwin-Austen shows that the Swindon Purbecks absolutely alternate with beds containing a Portland fauna. Just as, in more recent times, sections occur at the edge of the great belt of blown sand surrounding the Lancashire coast. The sand resting on the great peat plain contains seams of peat with freshwater shells, alternating with bands of sand, which become thicker and thicker in the upper parts of the sections, the sand having gradually silted up the peat-morass, and the freshwater shells being replaced by rolled and wind-worn seashells.

Everywhere, indeed, in the geological formations, a change of sediment appears to have brought a change of fauna, and in most cases a recurrence of physical conditions induced a return of the old fauna. In these cases it is clear that the change of sediment, and of other physical conditions, depth of sea, of temperature, air and water, must have been local, though possibly extending over large areas, and that extinction of a species could only have taken place when the area of change was coincident to, or greater than, the area of habitat of that species. The longer the time elapsing during the period of change, the greater chance would hardy species have of migrating to more favourable areas, and of becoming naturalized to conditions, as to character of sea-bottom and depth, differing from those they had been accustomed to.

Mr. Bristow * represents the Isle of Portland as consisting, at St. George's Church, of—

1. *Purbecks,* resting on an eroded surface. 30 feet made up of alternations of fissile limestones (locally termed "Slate"), some of which afford small flagstones, with Clays and Marls. Towards the bottom of the series some of the beds of clay (the "Dirt" and "Black Dirt" of the quarryman) contain much carbonaceous matter, and the silicified remains of coniferous and cycadaceous plants, the roots and stumps of which retain their originally erect positions, while the trunks lie prostrate.

2. *Portland Stone.*—Bituminous limestone, occasionally Oolitic, with chert and flints, in bands and disseminated masses. These become very abundant towards the bottom of the series, when they frequently fill the joints of the beds. The freestone lies immediately beneath the Purbecks, and is extensively quarried for building purposes; 85 feet.

3. *Portland Sand.*—Ferruginous, occasionally marly (containing selenite and fibrous gypsum and carbonaceous matter), of a yellow and bluish-grey colour, becoming more clayey and blue at its junction with Kimmeridge Clay, into which there is a gradual passage; 150 feet.

4. *Kimmeridge Clay,* 160 feet to sea-level. At Veon Signal Staff, 280 feet. Going north, on the mainland, the Coral Rag, 290 feet thick, is sandy and ferruginous on the top, and consists of fossiliferous Limestones and Marls, sometimes Oolites, resting on the Oxford Clay; blue and brown shale, splitting on exposure to the air, and reaching 500 feet in thickness. Under it, the Cornbrash rubbly cream-coloured Limestones (never Oolitic) attain 50 feet, resting on 200 feet of Forest Marble, the base of which is not visible. It is an irregular accumulation of coarse, blue, shelly Limestones (sometimes Oolite), rippled flags and clays and sands, brought up by a low anticlinal axis, a little to the north of which the Kimmeridge Clay again comes in with

* 'Geological Survey of England and Wales.' Horizontal Sheet 20.

the overlying Portland and Purbecks, until they are cut off, by the great upcast fault throwing in the Chalk of Black Down, which rises to a height of 800 feet at the Hardy Monument, the top of the Upper Greensand then being probably about 70 feet lower, giving a thickness of Chalk of at least 870 feet. The Upper Greensand forms a useful building stone when it has hardened by exposure to the weather, reaching a thickness of 150 feet, and resting on the Kimmeridge Clay. The Chalk continues to West Hill, where the Upper Greensand and Kimmeridge Clay crop to the surface.

At Lillington Hill (430 feet high), 170 feet of Forest Marble overlies 180 feet of Upper Fuller's Earth, 20 feet of Fuller's Earth rock, 150 feet of Lower Fuller's Earth rock, and probably 70 feet of Inferior Oolite, cream-coloured Limestones, sometimes Oolites. Between Milborne Port and Sherborne, the beds charged with Oolitic grains of hydrate of iron, which generally occur at the base of the Limestone, overlie 20 feet of rubbly Limestones, in clay and sandy shales.

Swanage.—*Acres*, 3163; population, 2357; wells and springs; one spring yields 2000 gallons per hour; stored in reservoirs, supply constant; rateable value, 5986*l.* 15*s.*

Weymouth and Melcombe Regis.—Population, 13,704; springs in the Upper Greensand, 370,000 gallons; reservoirs holding 3,000,000 gallons; rateable value, 45,615*l.*; Weymouth Waterworks Act, 1855. Rainfall in 1879, at 200 feet above the sea, 35·44 inches.

Portland.—*Acres*, 3555; population, 10,046; springs and wells pumped; a supply from the *Chene Works*, belonging to the Admiralty, for the use of the village of Weston, Portland; rateable value, 18,849*l.* 17*s.* 1*d.* Rainfall in 1879 at Verne Citadel, 473 feet above Ordnance Datum, 34·11 inches.

RIVER BREDY (CLIV.).

Length, 7 miles; area, 21 square miles, 12 miles of which are Oolites, 3 Greensands, and 6 Chalk. The eastern

boundary is the Purbeck watershed running along the chalk hills, at the foot of which the feeders of this river rise in the Upper Greensands, and thence it flows over the Oolites to Little Bredy, where it has a V-shaped valley in the steep cliffs, at the foot of which commences the Chesil Bank, here consisting of small pebbles, which gradually increase in size eastwards, or in the direction of the flow-tide.

RIVER BRIT (CLIII.).

Length, 6 miles; area, 52 square miles, of which 14 are occupied by Lias, 24 by Oolites, 6 by the Upper Greensand, and 8 by Chalk.

Like the *BREDY*, its northern boundary is the chalk watershed separating the south-coast streams from the Vale of Poole; like it, it rises in the Upper Greensands at the base of the Chalk escarpment, and traverses the Oolites to the sea at Bridport Harbour, which is formed in the alluvial flat of the river at the bottom of a V-shaped valley. In this case the bottom of the "V" is probably concealed by shingle, and points to the land being relatively higher to the sea-level when the valley was formed by fluviatile denudation. The valleys further west at Golden Cap have not been cut down to the sea-level, and the bottom of the "V" is many feet above high-water mark, the water flowing down the side of the cliff.

Bridport.—*Acres*, 359; population, 6790; supply constant, 300,000 gallons, from reservoir at Litton Cheney, 6 miles distant; rateable value, 18,000*l.*; Private Act, 35 & 36 Vict., 1872. Rainfall in 1879, 36·60 inches.

Beaminster.—The Cretaceous rocks in the hills north of this town are plentiful in springs, especially in the Upper Greensand, which consists of the following divisions or zones from the base of the Chalk downwards. Rainfall in 1879, 44·56 inches.

Zone of Scaphites æqualis.—Beneath the Yellow Chalk of West Dorset and South Somerset a very constant bed of yellow calcareous paste, with glauconitic grains, occurs,

containing at the base numerous minute pebbles of quartz, the whole being so well cemented together as to be used at Pennys Toller, near Beaminster, as a rough building stone. In 1865 I collected from this zone a large number of fossils, most of which I found to occur in the so-called Cambridgeshire "Chloritic Marl," Chardstock, Buckram, and Pennys Toller, being perhaps the most fossiliferous localities. At the base occurs a well-marked horizon of *Ammonites Rothomagensis*.

Zone of Pecten asper. — A bed of dark brown-coloured quartzose sandstone, 20 feet thick, sometimes forms the top of the Upper Greensand. It is well seen at Seamark Hill, where it contains *Exogyra conica*, and at Tytherleigh. Eastwards, from Seamark to Buckram, it thins out, and overlies, and is partly equivalent to, a bed of light-green coarse-grained sandstone, about 16 feet in thickness, in which the *Pectens* occur. This portion of the bed is very constant, being seen in most of the sections on the top of the Oolitic hills from Chard in Somerset to Eggardon Hill in Dorset—a range of country more than 25 miles in length.

Zone of Exogyra conica.—These beds consist of very soft bright yellow (occasionally pale green-coloured) sand, with vast numbers of *Exogyræ*, often of very large size. Both the two last-mentioned zones are present at Blackdown. It is generally about 15 feet thick, and is usually present in all the Lower Cretaceous sections of East Devon, South-west Somerset, and West Dorset.

A comparison of many of the species occurring in the Phosphatic seams of the Lower Greensand (Upper Neocomian of Kent) with those from the junction bed "*Am. interruptus* Zone" of the Gault of Folkestone, the "nodule bed" dividing the Lower and Upper Gault of the same place, and with those of the zone of *Scaphites æqualis* (Chloritic Marl) of Dorsetshire and Cambridge, shows a striking number of species in common, and much resemblance in physical aspect,—rolled and water-worn shells, drifted wood bored by shells, rolled bones of Saurians, drifted pebbles, and

masses of phosphatic matter, which can sometimes be made out to be molluskite, probably of large *Rostellariæ*.

The facies of the whole suggests a beach and shore deposit, which is to a certain extent borne out by the habitats of the recent analogues of the species of shells of molluscs found associated. The recurrence of these species at the precise era of time when physical conditions were changing would appear to indicate the continuance of an old coast-line, from which the shells were washed by currents, which coast-line would appear to have continued throughout the whole period occupied by the whole of the Lower Cretaceous system of the South of England.

Why currents should have flowed from this old land at the moment when physical changes introduced changes of sediments is difficult to explain. Possibly the presence of the molluskite may be due to large quantities of fresh water coming down to this old coast-line, and killing large quantities of mollusca, their bodies being floated away by tidal or other currents. If the south-west of England was still land during the deposition of the Neocomian Beds, a portion of this old coast may possibly have been in Somerset and Devon.

RIVER CHAR (CLII.).

Length, 8 miles; area, 39 square miles, of which 30 are Lias and 9 Upper Greensand. The steady easterly dip of the Liassic series brings in successively the Lias Sands, the Marlstone, and the Lower Lias Shales; the latter, between Charmouth and Lyme Regis, contain a considerable thickness of cement stones and hydraulic limestones, but the greater part of the thickness of the Lias consists of impermeable material. Resting on the Lower Lias, especially near the coast, are the following cretaceous deposits, in descending order:—

Fox Mould.—The deposit locally known by this name consists of loamy sand. At Pinhay it reaches a thickness of 60 feet, and is nearly as thick at Black Ven, where it over-

lies the Cow Stones. In the latter locality it forms a loose shifting mass, through which the cutting of the Lyme Regis road has been carried, and has been the scene of numerous landslips. A species of *Belemnite* occurs in it, and one of *Pecten* at Wambrook Valley.

Cow Stones.—These silicious concretions occur immediately at the base of the Fox Mould at Alston, Chardstock, and Black Ven; they are often 6 feet in length, and constitute the zone of *Hoploparia longimana.* Of the former, 60 per cent. of the species are common to the Whetstones and other Blackdown Beds, and about 32 per cent. occur in the Folkestone Gault.

Gault.—This deposit occurs at Golden Cap, Stonebarrow, Black Ven, and Pinhay Cliff. It consists of dark grey-coloured stiff clay, difficult to distinguish from some beds of the Lias, on which it rests. At Black Ven, where it is perhaps best seen, it is divided from the Cow Stones above by a few feet of yellow sand. A comparison of the fossils found in this clay in the Museum of Practical Geology, and in the collection of Mr. Day, now amalgamated with the former, and in my own collection, with those of the Folkestone Gault, tends to correlate the Dorsetshire Gault rather with the *Lower* Gault of Folkestone than with the Upper, in which case, supposing the Whetstones in the Blackdown Beds to represent the Cow Stones, they and other portions of the former may be the equivalents in time of the Upper Gault.

The Fox Mould, Cow Stones, and Gault are absent in the inland Dorsetshire sections at Lewston and Seamark Hills, and Buckram, and the "*Exogyra conica* sand" rests upon a dark olive-green coloured sand, without fossils, and full of water. The sand is particularly well seen at Hooke Park, a few miles east of Beaminster, which sand is probably the equivalent in time of the Fox Mould of Lyme Regis, which is not present in the White Cliff section at Beer, where Sir Henry De la Beche considered the Fox Mould to be represented by greenish-yellow and brown sands, containing chert

nodules, resting on green sands with concretions of sandstones, the equivalents of the Cow Stones of Lyme Regis.

In the Beer section the *Exogyra* and *Pecten asper* zones are represented by numerous bands of yellowish-brown Sandstone, with green earth, and chert seams, and nodules. The base of the Chalk line is extremely compact and silicious, and is the equivalent of the Chalk with quartz grains of Pennys Toller and Lyme Regis, and the "Beer stone" of the quarries of Beer.

Before leaving the description of the Cretaceous Beds of this area, it may be well to mention the vast sheets of more or less angular gravels occurring on the tops of all the Cretaceous hills. In the upper portion the flints are slightly rolled, and mixed with numerous rolled quartz pebbles. In the lower portion the ground often consists of masses of fractured chert, resting on a yellow clay, occurring more or less in pot-holes, with long gnarled black-coated flints. The whole series is well seen at Wambrook Valley, Alston, Tytherleigh, Lewston, Seamark Hill, White-sheet Hill, Cotleigh Hill, Pennys Toller, Hooke Park, and Golden Cap.

Charmouth. — Supplied by springs conveyed to the village.

Lyme Regis.—*Acres*, 1391; population, 2296; from springs; unlimited; rateable value, 978*l.* 5*s.*; authority from Corporation.

RIVER AXE (CLI.).

Length, 18 miles; area, 159 square miles, of which 24 miles consist of Trias, 15 of Lias, 6 of Oolite, 114 of Upper Greensand, and 6 of Chalk. An important watershed separates the streams flowing into the Bristol Channel from those flowing into the English Channel; it commences at the point where the diagonal watershed follows the remarkable change of strike in the Cretaceous rocks north of Beaminster, already described. It continues the west-north-west direction of the Purbeck portion of the diagonal watershed, but, unlike it, does not follow the strike of the rocks over

which it passes, but crosses the Oolites at Crewkerne, the Lias and the Cretaceous rocks at Chard, the Red Marls of the Vale of Taunton, the Culm Measures and Devonian rocks of Exmoor, reaching the Bristol Channel at Ilfracombe.

The *AXE* and its tributary the *Yar* both rise in the Upper Greensand Beds traversed by the West Somerset watershed just described. The *AXE* flows over the Oolites and the Lias to Axminster, where it enters on the New Red Marls, and receives the latter stream, which drains a Keuper Marl valley, capped by Cretaceous sands. These are well seen on the coast at Beer Head, where they have been described by Mr. C. J. A. Meyer,* who divides them into three groups, the Blackdown Beds (= zone of *Ammonites inflatus* of Dr. Barrois), the Upper Greensand, the Warminster Beds (= zone of *Pecten asper*, Dr. Barrois), and then the Chalk Marl. Mr. Meyer considered the Warminster Beds to be equivalent to the Chloritic Marl, but as Warminster Beds have subsequently been found in the Isle of Wight associated with the Upper Greensand, and beneath the Chloritic Marl, this correlation will not hold, and his second and third divisions belong to the same formation. Dr. Barrois gives a thickness of 75 feet to the *Am. inflatus* zone and of 21 feet to the *Pecten asper* zone at Beer Head.

Axminster.—*Acres* in registration sub-district, 18,640, with 5186 inhabitants.

Seaton.—*Acres*, 1099; population, 1221; from a spring three-quarters of a mile from the town, conveyed by iron pipes, and wells; rateable value, 524*l.* 15*s.* Rainfall in 1879, at 126 feet above the sea, 42·40 inches.

Axemouth.—[No information.]

STREAMS: O.S. CATCHMENT BASIN CL.

Area, 21 square miles, of which 3 are Keuper Marls and 18 Upper Greensand. This small basin occupies a triangular tract of country extending a short distance inland,

* 'Quart. Jour Geol. Soc.,' vol. xxx. p 369.

intervening between the basins of the *AXE* and the *OTTER*. Salcombe Regis, Sidbury.

RIVER OTTER (CXLIX.).

Length, 15 miles; area, 82, of which 22 are Triassic Marls, 30 Triassic Sandstones, and 30 Upper Greensand, in which deposit the river rises immediately under the watershed overhanging the Vale of Taunton.

SIDMOUTH.—*Acres*, 1540; population, 3501; private wells and tank supplied by a spring at Cotmaton; supply limited; 12,834*l.* 5*s.* Rainfall in 1879, at Sidmount, 149 feet above Ordnance Datum, 37·65 inches.

HONITON.—*Acres*, 2815; population, 3349; wells, town reservoir, public springs; supply, 266 hogsheads; rateable value, 11,481*l.* 15*s.*

OTTERY ST. MARY.—*Acres*, 9945; population, 4005; intermittent supply from springs, conveyed to iron tank holding 1700 gallons, three-quarters of a mile from the town; rateable value, 18,077*l.*; Public Health Acts, 1848 and 1875.

RIVER EXE (CXLIV.).

Length, 55 miles; area, with tributaries, 584 square miles, of which Devonian rocks occupy 110, Carboniferous rocks 200, Triassic Sandstone 252, and Upper Greensand 22. Northward and eastward this basin is bounded by the West Somerset watershed, westward by that of the *TAW*, flowing into St. George's Channel. It rises in Somersetshire near Dunkerry Beacon in Exmoor, only 5 miles from the Bristol Channel at East Lynn, on the Devonian rocks. Its tributary the *Barle* (west bank), 16 miles long, also traverses entirely Devonian rocks, falling into the main stream near the point where the Culm Measures come in. At Tiverton the *Loman*, 6 miles long, falls in on the east bank, draining chiefly a Triassic district. At the same point falls in a canal running into the valley of the *Tour*, a tributary of the *PARRET*, crossing the West Somerset water-

shed, west of Wellington, nearly at the same place as it is crossed by the Great Western Railway's Exeter and Taunton line. On the east bank also falls in the *Culm*, 17 miles long, rising in the Upper Greensand, south of Wellington, and traversing New Red Marls and New Red Sandstones. A western tributary, the *Dart*, 8 miles long, falls in half-way between the outfalls of the *Loman* and *Culm*, and drains a Culm Measure tract. Another western tributary, the *Creedy*, falls in nearly opposite the outfall of the *Culm*, immediately above Exeter, draining Triassic rocks up to Crediton. The *Yeou*, 13 miles long, is tributary to the *Creedy*, and rises under Cawsand Beacon, 792 feet high. Beside the *Creedy* runs a canal from Exeter to Crediton.

Crediton.—*Acres*, 2402; population, 4220; two public wells with pumps, kept in repair by voluntary subscription; rateable value, 9727*l*.

Bampton.—*Acres*, 129; population, 1111; main is laid from a spring in the rock a quarter of a mile distant, and private wells; Public Health Act, 1848–58.

Tiverton.—*Acres*, 17,491; population, 10,025; wells; rateable value, 43,075*l*. Rainfall, in 1879, at 280 feet above the sea, 39·70 inches.

Exeter.—Population, 37,608; supply abstracted from the *EXE*, above its junction with the *Culm*, 45 miles from its source, and $1\frac{3}{4}$ miles from the pumping station at Pynes' Leat, when the water is lifted by steam and water power into two open reservoirs holding nearly 4,500,000 gallons. Rainfall varied in 1879, in different localities, from 32·99 inches at Brockhill to 41·43 at the Quarries. Mean annual rainfall at the Exeter Institution, 155 feet above Ordnance Datum :—

1850–9.	1860–9.	1870–9.
26·91	31·76	34·69

The Rivers Pollution Commission states that the *EXE* at this point is a soft, unpolluted stream, suitable for all purposes except the brewing of pale ale. Occasionally, however, it is subject to sewage contamination, probably from Tiverton.

The hardness rises from 4·9 to 5·9, all of which is permanent. The quantity supplied is 1,500,000 gallons; rateable value, 163,403*l*. The works were constructed under the Exeter Water Act, 3 Geo. IV. c. 32, and were transferred to the Corporation, 2nd July, 1878, under their Act of that year.

Mr. S. Stooke, C.E., informs me that 47,000 gallons of water for the drinking fountain of Exeter is daily derived from the Lyons Holt Spring near the city, in the New Red Sandstone, 126 feet above the sea. Its analysis by Mr. Perkins shows it to be of great purity.

Messrs. Norman and Pringlitz's Brewery well is 25 feet above the sea, and 70 feet with adits and 4-inch boring to 270 feet, yields 5000 gallons a day, and does not vary in level. The water contains of chloride of sodium 4·79 grains per gallon, 9·75 of carbonate of soda, and 6·24 of sulphate of lime. From the section given this well would appear to be in the Culm Measures.

At Messrs. Gillman's well, Treus Weir, the surface is 20 feet above the sea; it has a 7-inch borehole; it is 240 feet deep, yielding 250,000 gallons a day for 10 years; a large volume is found in autumn and spring, but the well is not affected by rain. The boring is in the Red Sandstone.

At Kensham Mills, Hele, Mr. Drew states that the surface is 100 feet above the sea; there is a 5-feet well of 40 feet, and a 7-inch boring carried 200 feet, yielding 170,000 gallons from New Red Sandstone.

At Hele Paper Works, Mr. C. R. Collins states the surface is 90 feet above the sea; a well of 10 feet diameter is carried 20 feet, and a 6-inch boring to 120 feet; yields 259,000 gallons a day from the New Red Sandstone. The water-level diminishes 20 feet in dry weather.

At Bridge Mills, Silverton, Mr. J. M. Drew states the surface is 80 feet above the sea; a 4-feet well is carried 20 feet and a 6-inch boring 217 feet; yields 180,000 gallons a day from the New Red Sandstone.

Exeter (St. Thomas the Apostle).—*Acres*, 3700; popula-

tion, 6161, of which 4000 are supplied by Local Board, from a well giving 115,000 gallons a day; 500,000 gallons stored in reservoir, water of 7° of hardness; also supplied by Exeter Corporation; rateable value, 20,035*l.*; Public Health Act and Exeter Corporation Act.

Exminster Lunatic Asylum (per Messrs. W. Shepherd and Son).—Well 100 feet above the sea; 9-feet shaft 117 feet deep, with 6-inch bore to 473 feet from surface; water-level 30 feet above bottom of shaft after pumping 12 hours; 25 feet restored in 6 hours; quantity, 200,000 gallons from conglomerate of New Red Sandstone.

Exmouth.—*Acres*, 460; population, 6245; supply from springs in gravel, Squab Moor; 120,000 gallons daily stand in reservoir; water very soft and pure; rateable value, 20,053*l.*; Exmouth and Budleigh Salterton Waterworks Act, 27 & 28 Vict. c. 249. Rainfall in 1879 at East Budleigh, 70 feet above Ordnance Datum, 38·39 inches.

ORDNANCE SURVEY CATCHMENT BASIN CCI.

Area, 11 square miles, of which 9 are New Red Sandstone and 3 Upper Greensand. This small basin occurs between the *TEIGN* and the *EXE*, and contains the most westerly exposure of Cretaceous rocks in England.

Dawlish.—*Acres*, 1316; population, 3997; private surface wells; Local Board have obtained provisional order for construction of reservoir; rateable value, 17,931*l.* Rainfall in 1879, 120 feet above the sea, 41·92 inches.

RIVER TEIGN (CC.).

Length 27 miles; area, 203 square miles, of which Granite and Igneous rocks occupy 70, Devonian 10, Carboniferous Limestone 3, Carboniferous rocks 80, Triassic Sandstones 31, Miocene Tertiary 9. The streams flowing into West Bay extending from Portland Bill to Start Point form a natural group, bounded to the north first by the Purbeck watershed then by the "West Somerset" extending to

Exmoor, and west by the Central Devon, ranging from the West Somerset on Exmoor by Cawsand Beacon, across Dartmoor, thence trending south-east to the English Channel at Dartmouth.

This watershed commences on the Devonian rocks of North Devon, and terminates in the rocks of the same age in South Devon, crossing the Carboniferous rocks which fill in the synclinal between these two belts of rock, occurring nowhere else in the British Isles, with the one exception of the rocks found under the London Cretaceous in Meux's boring. The southern boundary of the Culm Measures and the Devonian is broken by the intrusion of the Dartmoor Granite, rising to a height of 2000 feet, forming a series of rolling moors, enlivened only by Granite tors, in which meet nearly all the lines of watershed in West Devon. In this granitic mass rise the Rivers *TEIGN, DART, AUNE, ERME, YEALM, WALLCOMB, PLYM,* and tributaries of the *TAMAR* flowing south, and the Rivers *TAWE* and tributaries of the *TORRIDGE* flowing north. The feeders of the two last rivers springing but a short distance from those of the *TEIGN* and the *DART.*

Moreton Hampstead (Teignmouth).—*Acres,* 1074; population, 7100; reservoir near, and another a mile distant, near Haldon, filled from *Combe* or *Bitton Brook* rising on Haldon springs on Exeter road, and wells in *Combe* valley; 25 gallons per head; intermittent in summer; Teignmouth Improvement Act, 6 Will. IV. c. 59, 1836; Local Government Act, 1858.

Torquay.—*Acres,* supply area, 1200; population, 24,765. The whole of a stream flowing off Dartmoor, 2 miles from its source and 16 from Torquay, is directed into a reservoir holding 80,000,000 gallons, thence it flows into three service reservoirs of 2,500,000 gallons each. The minimum flow of the stream after 5 months' drought was 151,000 gallons daily. The Rivers Pollution Commission states the total solid impurity to be 6·36, the total hardness 2·3, but it contains too large a proportion of organic matter for perfect safety;

Supply 650,000; intermittent; duplicate main and another reservoir are in course of construction; rateable value, 109,000*l.*; the Torquay Waterworks Act, 1856. Rainfall in 1879, at Lamorna, 200 feet above Ordnance Datum, 41·54 inches.

Newton Abbot is supplied by Torquay Waterworks Company.

Woolborough.—*Acres*, 1230; population, 7662; *Torquay Waterworks Company;* rateable value, 20,959*l.* 7*s.* 9*d.*

St. Mary's Church.—*Acres*, 1536; population, 5759; by *Torquay Waterworks Company;* rateable value, 16,060*l.*

RIVER DART (CXCIX.).

Length, 35 miles; area, 200 square miles, of which Granite and Igneous rocks occupy 50, Devonian 141, Carboniferous Limestone 2, Carboniferous rocks 5, New Red Sandstone 2.

This stream is the last of the West Bay group; its western margin is the Central Devon watershed. It runs, as before stated, in the Granite of Dartmoor, and, passing Ashburton and Totnes, opens out in the wide and picturesque estuary at Dartmouth.

Dartmouth.—Population, 5580; supply from springs stored in reservoir, 200,000 gallons a day; rateable value, 15,843*l.* 15*s.* 7*d.*; Public Health and Local Government Acts. Rainfall in 1879, at Street, 200 feet above the sea, 43·90 inches.

Lower Brixham. — *Acres*, 5363; population, 4941; a spring near Laywell, Higher Brixham, two service reservoirs 50 feet from spring; estimated at 66,096 gallons, but not confined to that quantity (c.); rateable value, 9912*l.*; 11 & 12 Vict. c. 63, s. 75.

Paignton.—Population, 4610; part of, by a private Company from springs south of the town. Rainfall in 1879, at Hollacombe, 70 feet above the sea, 39·13 inches.

Totnes.—*Acres*, 1427; population, 4089; two springs on

Broomborough Estate, in the borough, about half a mile from two reservoirs of total capacity of 190,000 gallons; 17,000 to 25,000 a day; intermittent; rateable value, 13,965*l.* 17*s.* 6*d.*; 8 & 9 Vict. c. 134. The supply is stated by the Local Board not to require improvement, but the Rivers Pollution Commission describes it as "inadequate."

CHAPTER XVIII.

STREAMS WEST OF THE CENTRAL DEVON WATERSHED AND SOUTH OF THE CENTRAL CORNISH WATERSHED.

Sea-coast—Start Point to Land's End.

O.S. CATCHMENT BASIN CCII.

AREA, 73 square miles, all of which are occupied by Devonian rocks, and certain altered strata at Bolt Head and Start Point of doubtful age. The estuary of the various streamlets draining this tract is deeply indented, and extends inland a considerable distance.

RIVER AUNE (CXCVIII.).

Length, 19 miles; area, 54 square miles, of which 8 are granite and 46 Devonian rocks.

RIVER ERME (CXCVII.).

Length, 12 miles; area, 43 square miles, of which 12 are granite and 43 Devonian rocks: like the *AUNE*, this stream rises in the granite of Dartmoor, as do the three following.

RIVER PLYM (CXCV.).

Length, 8 miles; area, 59 square miles, of which 10 are granite and the remainder Devonian.

River *PLYM* at Sheepstor, according to Mr. Beardmore, drains 7·6 square miles, ranging from 800 to 1500 feet elevation, discharges 500 cubic feet of water per minute, or 71·4 cubic feet per minute per square mile, representing a fall of 15·10 inches per annum, out of an actual average fall of 45 inches, or about one-third of the precipitation.

RIVER YALME (CXCVI.).

Length, 9 miles; area, 36, of which 5 are granite and 31 Devonian.

Ivybridge.—Population, 1820; supply from springs, supplemented in summer by river *ERME;* 16,000 to 25,000, constant; rateable value, 428*l.* 6*s.* 10*d.*; Public Health Act, 1848, Local Government Acts, 1858, 1861, and 1866.

PLYMOUTH LEAT (CXCIV.).

Length, 19 miles; area, 23 square miles, of which 10 are granite and 13 Devonian rocks.

Plymouth.—*Acres*, 1465; population, 75,096; Corporation Waterworks, established in 1855, abstract waters of river *Mew* on Dartmoor, at a point 3½ miles from its source; the water flows into 4 service reservoirs holding 11,540,000, of which 3,500,000 gallons is delivered daily unfiltered, but constant; hardness, according to Rivers Pollution Commission, 2·1, of which all was permanent; total solid impurity, 3·50; chlorine, 1·30; temperature, Centigrade, 12·5; the Rivers Pollution Commission, commenting on this and other analyses of waters from the Granite and Gneiss, states that unpolluted spring water from these formations "is quite wholesome, and of most excellent quality for drinking, cooking, and all domestic purposes. As it issues from the spring, it is clear, bright, and palatable, and preserves throughout the year a nearly uniform temperature, which varies from about 12°·5 C., in the south of England, to 6°·5 C., in the north of Scotland. It is thus, like other spring waters, cool and refreshing in summer, and, in England at least, far removed from the freezing point in winter. The more disintegrated and weathered the rock, the freer will be the water from organic matter." Rainfall in 1879, in the Navigation School, 75 feet above Ordnance Datum, 42·02 inches.

East Stonehouse.—*Acres*, 190; population, 15,125, of these 2000 are marines and government officials, having a separate supply; the Devonport Company also supply about

60 houses. Supply from a spring, the head of which is at Tor, in the tything of Pennycross near Plymouth, and partly from reservoirs of the Corporation of Plymouth, who contracted to supply 600,000 gallons per week for 3 years from June 24, 1876. Supply about 180,000 to 200,000 gallons; rateable value, 34,356*l.* 15*s.*; the East Stonehouse Waterworks Act, 1851.

RIVER TAVY (CXCIII.).

Length, 19 miles; area, 85 square miles, with its tributary the *Wallcomb*, 12 miles in length; 9 square miles of this basin is occupied by granite and 76 by Devonian rocks. It is the most western of the streams flowing south, rising in the granite of Dartmoor, and having for the north-eastern boundary the Central Devon watershed. On the main stream are Saltash, Devonport, and Brent Tor; on the *Wallcomb* are Walkhampton, Sampford Spring. Tributary to this stream is the *Tay Cleave*, also rising in the Dartmoor granite, on which is Tavistock, from which a canal runs to the navigable part of the *Tamar*.

Devonport.—*Acres*, 1705; population 48,745; supply abstracted from *WEST DART* and tributary streams in basin of the *DART* in the forest of Dartmoor; stored in a service reservoir; the water is very soft, but peat-stained; the supply is constant; rateable value, 75,362*l.*; under 33 Geo. III. c. 85. Rainfall in 1879, at Rowden's Reservoir, 202 feet above Ordnance Datum, 43·09.

The granite of Dartmoor is for the most part porphyritic, containing schorl in variable proportions; sometimes globular masses reaching a foot in size occur, sometimes being much harder than the surrounding rock, and sometimes crumbling away by mere exposure to the weather; it is in these latter belts of small coherence that the curious "rock basins" are found, described at length by Mr. G. Wareing Ormerod, the result, in his opinion, of decomposition of the granite from water on the surface penetrating its mass during wet weather, and its subsequent evaporation, disintegration ensuing during

dry weather. Where vertical joints, and consequently unbroken faces resisting the passage of water, are found, no basins are seen; the largest described is 42 feet by 54, with a depth of 5 inches; the flat bottom found in most of them is doubtless due to the tabular horizontal joints which traverse the granite of Dartmoor, and give it a stratified appearance. The basins occur in a central belt occupying one-third of the moor. These occur on Tavy Far Tor, immediately north of the highest point of Dartmoor, 2000 feet above the sea-level. On Mistor Tor occurs the Mistor Pan, which is described as artificial in Rowe's 'Dartmoor,' and Bray's 'Tamar and Tavy.' Atmospheric action is well seen in the large basin on Bell Tor, east of the East Weber. In the same area is Hounter Tor, one of the most picturesque of the Dartmoor Tors; no basins occur on it, or on the Bowerman's Nose, or Manaton Tors.

Sir Henry De la Beche describes two granite "Elvans" in the carbonaceous series north of Dartmoor, one running through Lidbridge and Lidleigh Ball on the south-west of Hatherleigh, and the other west of Arscot, near South Zeal. Similar veins are described in these rocks north and east of Dartmoor by Mr. Ormerod at Meldon, and the gorge of the *TEIGN*, after leaving the granite at Chagford, is intersected by them. The cliffs known as Sharpy Tor, below the Logan Stone, are seamed with veins.

In the mining district of Cornwall four large and several small protrusions of granite occur in the "Killas" or clay-slate, the cleavage planes of which dip from these masses at a less angle than the line of contact between the two, along which the granite generally becomes fine grained, and throws off veins. The granites of Cornwall are probably of the same geological age, and were upheaved during post-Carboniferous times. Near the granite the slates are of a violet, purple-green, or brown hue; but at a distance from it they are brownish yellow, deep blue, bluish-grey, or grey. In the western area of the mining district they are unfossiliferous, but in the eastern part of the district the organisms indicate a Devonian age both for the Killas and associated beds of

limestone, though some of the rocks of south-western Cornwall may be of Silurian age.

Both granites and slates are intersected by dykes of granite or quartz-porphyry, known as "elvan courses," varying in width from a few feet to many fathoms, and which generally run north of east and west of south. In addition to this ejection of elvans, there is evidence of the outpouring of large volumes of igneous rocks, including doleritic lavas, during the deposition of the Devonians, and prior to the post-Carboniferous eruption. The veins yielding tin and copper generally run east and west, and occur near the junction of the granite and killas, and are known as "lodes"; those intersecting them at right angles, known as cross-veins, sometimes yield lead and iron ores when in the vicinity of lodes, while those intersecting the true lodes at acute angles are termed "caunter lodes," and are often metalliferous.

RIVER TAMAR (*CLXXXVII.*).

Length, 38 miles; area, 385 square miles with its tributaries, of which 10 miles are occupied by Granite, 120 by Devonian, and 255 by Carboniferous rocks, all of which are in great measure impermeable.

This river forms the county boundary between Devon and Cornwall, and like the river *EXE* rises within a few miles of the Bristol Channel, and flowing south-south-east traverses the county to the English Channel.

On the east bank of the *TAMAR* fall in the tributaries, the *Claw*, the *Carey*, the *Lew*, with sub-tributaries, the *Thistle Bridge* and the *Lyd*, on the west bank the River *Attery*, on which is Launceston. From the point where the river falls into the main stream a canal is carried parallel to the river, to a point 7½ miles distant from its source, and 5 miles from the sea crosses the central Cornish watershed south of Stratford, and is carried to the Irish Sea. The *TAMAR* and all its tributaries to the *Attery* drain the Culm Measures; below the outfall of this river the Devonian rocks set in, and continue to the coast.

In the Devonian area, on its west bank, it receives the *Inny* and its sub-tributary the *Yenport*, nearly coinciding in position and direction with the boundary between the Culm Measures and the Devonian rocks. The estuary of the *TAMAR* extends inland 10 miles, and is navigable a further 7 miles to a point where the river has attained an elevation of 49 feet above the sea. The *TAVEY*, already described, falls into the estuary on the east bank, and the river *LYNHER* on its west bank.

LAUNCESTON.—*Acres*, 2000; population, 3808; springs stored in reservoirs; constant 30,000 to 100,000 gallons per day; rateable value, 12,022*l.*; Public Health Act, 1848, 1875, 38 & 39 Vict. c. 55.

RIVER LYNHER (CXCII.)

Length, 23 miles; area, with tributaries, 100 square miles, of which 8 are granite, and the remainder Devonian rocks.

The most extensive exposure of granite in the south-west of England, that of Dartmoor, is wholly in the county of Devonshire west of the *TAMAR;* four tracts of this rock rise to the surface, and form the back-bone of Cornwall, the central watershed in each traversing them, but generally keeping much closer to the northern margin than the southern. The first of these, it will be convenient to call the eastern boss, then the east central or St. Austell boss, the west central or Redruth boss, and the western or Land's End boss, each of which gives rise to streams flowing to the north and to the south.

On the *LYNHER* are St. Germans and North Hill. The tributary stream, the *Tidi*, falls in on the west bank near the estuary, and is navigable for a short distance from the coast; on it are Landrake and Sheviock.

O.S. CATCHMENT BASIN CXCI.

Area, 71 square miles, the whole of which consists of Devonian rocks. The central stream has a canal parallel to

it, from Looe on the coast up to Liskeard, 156 feet above the sea.

Liskeard.—*Acres*, 830; population, 4479; springs at Poke Tor and Sibly Back, forming two small streams known as *Iscar* and *Cryllay*, in the parish of St. Cleer; stored in reservoir holding 545,500 gallons; supply, constant 300,000 gallons; reservoirs on St. Cleer Down, 2 miles from Liskeard; public wells in "killas"; rateable value, 14,224*l.*; Liskeard Waterworks Act, 1860, 23 & 24 Vict.; the hardness of the water from the wells in the Devonian was 10·9 and 7·7, all of which was permanent (Rivers Pollution Commission); hardness of public supply 2·2, of which 1·9 was permanent. Rainfall in 1879, at St. Cleer, 620 feet above the sea, 50·53 inches.

RIVER FOWEY (CXC.).

Length, 19 miles; area, 120 square miles, of which the eastern granitic boss occupies 35 miles, and the east central boss 10 miles, and Devonian rocks 75. Fowey and Lostwithiel are in this basin.

O.S. CATCHMENT BASIN CCVI.

Area, 80 square miles, of which 26 consist of granite (east central boss), and 54 of Devonian rocks.

St. Austell.—*Acres*, 186; population, 3612; reservoir holds 300,000 gallons, collected from two sets of springs in the Granite conducted to one channel; supply, constant, unfiltered, 106,500 gallons. The Rivers Pollution Commission states the public supply to be free from organic impurity. Total solid impurity is stated to be 7·88. Total hardness, 2·3, of which all is permanent. A spring in a clay pit gave a similar analysis, with a temperature of 9°·3 C. Rateable value, 10,359*l.* Works cost 1000*l.*, raised by the Town Council by voluntary subscription. Grampound and Tregony are in this basin. Rainfall in 1879 varied from 49·68 inches at Cosgarne, to 55·55 at Polcarne, 206 feet above the sea.

Four streams draining into the Falmouth estuary are considered separate basins by the Ordnance Survey.

RIVER FAL (CCV.).

Length, 16 miles; area, 50 square miles, of which the east central granitic boss occupies 16, the remainder consisting of Devonian rocks.

O.S. CATCHMENT BASIN (CCIV.).

With an area of 66 square miles of Devonian rocks, drained by the central stream of this group. This coast is very deeply indented, and tidal for a considerable distance inland. The eastern feeder has only attained an elevation of 16 feet above the mean sea-level 4 miles from the central Cornish watershed, and the western feeder is only a foot higher at Truro, which is 3½ miles from the watershed and 9 miles from the open sea.

Truro.—*Acres*, 1103; population, 10,663; 27 private wells (Waterworks constructing by private Company), vary in depth from 9 to 70 feet; public pump (well 25 feet deep) in Boscawen Street, stated by Rivers Pollution Commission to be of very doubtful quality; the total solid impurity was 54·46, and total hardness, 26·0, of which 15·4 was permanent; rateable value, 23,074*l.* 13*s.* 9*d.* Rainfall in 1879, 56 feet above Ordnance Datum, was 41·64 inches.

The Commissioners state "waters from shallow wells in or upon Devonian rocks are, as a rule, much more polluted than those situated in Silurian strata." Out of 25 samples of well waters from the Devonian rocks of Cornwall and South Devon, only 8 were fit for human consumption. Of these 25 waters the hardness ranged from 5·0, at Mr. Boon's well, Ivy Bridge, Devon, to 44·3, at the Fort Pump, New Quay, Cornwall.

O.S. CATCHMENT BASIN (CCXI.).

Area, 40 square miles, of which 18 are occupied by a portion of the west central granitic boss; the remaining 22 miles are Devonian rocks.

O.S. CATCHMENT BASIN (CCXII.).

Area, 12 miles, of which about 2 form part of the west central granitic mass, and the remainder are occupied by Devonian rocks.

FALMOUTH.—*Acres*, 40; population, 4373; reservoirs; collected from peat-covered granite, water soft but peat-stained; supply constant to 130 feet, intermittent up to 190 feet above the sea; works cost 23,000*l.*; rateable value, 9356*l.* 4*s.* 3*d.*; Falmouth Waterworks Acts, 1847 and 1862. Rainfall in 1879, at Carclew, was 50·02 inches.

These works also supply:—Falmouth Parish, *acres*, 830; population, 4700; rateable value, 17,940*l.* In all, a population of about 12,000.

PENRYN.—*Acres*, 289; population, 3463. *Falmouth Waterworks* and a watercourse belonging to the town. The *Falmouth Waterworks'* reservoirs are at Antron Moor, a mile from the town. The Rivers Pollution Commission states the water to be slightly charged with the products of manured cultivated land. The total solid impurity is 8·76; total hardness, 2·7, all of which is permanent; chlorine, 2·75; rateable value, 7112*l.* 12*s.* 3*d.*

Budock is also in this basin.

RIVER HELFORD (CCXIII.).

Area, 33 square miles, of which the west central granitic mass occupies 10 square miles, the remainder being Devonian rocks. The estuary of the central stream extends into the county for several miles in a westerly direction; the streams rise near the low watershed separating this basin from the *HELSTON BASIN (CCX.)*.

O.S. CATCHMENT BASIN (CCXIV).

Area, 10 square miles, half of which are Devonian rocks, and half the Serpentine rocks of the Lizard Head. Anthony and St. Martin are in this basin.

O.S. CATCHMENT BASIN (CCXV.).

Area, 33 square miles, contains the Lizard Head, and, with the exception of 7 miles of Devonian rocks in the north-west corner, the whole of it consists of the altered rocks of the Lizard.

O.S. CATCHMENT BASIN (CCX.).

Area, 29 square miles, of which the west central granite boss occupies 10 square miles, all the feeders of the principal stream rising in it, near the central Cornish watershed. The estuary extends inland for 2 miles, and at Helston has only reached an elevation of 26 feet above the mean sea-level, at a point a mile distant from the source of the *HELFORD*, which flows in a direction at right angles to the Helston stream. The western boundary of the basin is the central Cornish watershed, which here has its prolongation to the Land's End interrupted, and the sea-coast for two miles west of this basin is drained by "*BASIN CCIX.*," which extends from sea to sea, and its southern margin is formed by cliffs, instead of by the central Cornish watershed, which has been destroyed by denudation.

HELSTON.—*Acres*, 292; population, 3432; wells and pumps; rateable value, 840*l*. The wells and springs from the Devonian rocks analyzed by the Rivers Pollution Commission are all dangerously polluted.

O.S. CATCHMENT BASIN (CCVIII.).

Area, 40 square miles, of which half consists of the Granite of the Land's End. Numerous small streams take their rise in it, and then flow across the Devonian rocks to the sea. The entire eastern, northern, and north-western margin of the watershed is formed by the central Cornish watershed.

PENZANCE.—*Acres*, 486; population, 11,684; augmented greatly in the season; waterworks were established in 1850, and belong to the Urban Sanitary Authority; the reservoirs

hold 6,000,000 gallons; the supply is constant; the water is abstracted from a stream, and the minimum daily supply is 150,000, maximum 520,000 gallons; it is not filtered or pumped, and is stated by the Rivers Pollution Commission to be polluted by cattle to some extent before entering the reservoirs; total solid impurity is 11·20, total hardness 3·0, the whole of which is permanent. Rainfall in 1879, at South Parade, 94 feet above the sea, was 50·07 inches; in 1880, was 43·04. Mean annual rainfall:—

1860–9.	1870–9.
41·51	46·80

Springs at Madron yield water of a temperature of 11°·8 C.; total solid impurity, 8·44; total hardness, 3·2, all of which are permanent. Springs at Alverton gave 12°·3 C.; total impurity, 25·36; total hardness, 9·4, of which 8·9 was permanent. The Rivers Pollution Commission states these springs to be clear, wholesome, and palatable, and they further state springs from the Devonian rocks and Old Red Sandstone furnish water which is generally of most excellent quality. They contain more calcareous matter than that from the Silurian or Igneous rocks. Rateable value, 33,510*l.* 9*s.* 3*d.* Under Public Health Act, 1875.

Madron.—*Acres*, 5476; population, 2791; church, town, village; tank giving 15 gallons per head; wells and springs; rateable value, 13,141*l.*

Ludgvan.—*Acres*, 4504; population, 2682; springs; rateable value, 7887*l.*

O.S. CATCHMENT BASIN CCVII. (in part).

Area, 27 square miles, the whole of which consist of the Land's End Granite. Its western boundary is formed by the termination of the central Cornish watershed, which reaches the sea immediately south of the Land's End promontory.

Camborne.—*Acres*, 6744; population, 13,607; reservoir giving constant supply of 20 gallons per head, from springs

in granite at Blackrock, Crowan, 4 miles distant. These, the Rivers Pollution Commission states, issue at a temperature of 10°·8; have a total solid impurity of 7·31; chlorine, 3·10; total hardness, 2·7, of which 1·9 is permanent; rateable value, 29,366*l.*; Camborne Water Act, 1867.

Hayle.—*Acres*, 250; population in 1881, 1089; reservoir storing spring supply 30,000 constant; rateable value, 3992*l.*; Local Government Board Act, 1875.

Phillack.—*Acres*, 2527; population, 3643; five public wells and many private; rateable value, 7239*l.*; contains also St. Erth and St. Breage.

CHAPTER XIX.

STREAMS NORTH OF THE CENTRAL CORNISH WATERSHED.

Sea-coast—Land's End to Baggy Point.

O.S. CATCHMENT BASIN CCVII. (in part).

This portion of the basin contains 20 square miles, consisting wholly of the Land's End Granite; the eastern margin is a very low watershed, being only 49 feet on the summit-level overlooking the Penzance basin. In this basin, including the portion draining south into the English Channel, are St. Paul, St. Levan, St. Just, and Morvah.

O.S. CATCHMENT BASIN (CCI.).

Area, 11 square miles, of which 7 are Land's End Granite, and about 3 Devonian; on the latter is situated St. Ives.

St. Ives.—*Acres*, 1876; population, 6441; tanks impounding 55,000 gallons from 3 streams supply 88,000 gallons daily, established about 1840, transferred to Corporation, 1866; rateable value, 14,266*l.*

Zennor.—[No information.]

O.S. CATCHMENT BASIN (CCIX.).

Area, 43 square miles; this remarkable basin has a coastline in St. George's Channel of 5 miles on the outfall side, and 2 miles in the English Channel on the side of its source, its southern margin having been destroyed, as already described.

O.S. CATCHMENT BASIN (CCIII.).

Area, 154 square miles, of which 7 form part of the west central granitic mass, and the remainder Devonian Rocks.

Gwithian, Redruth, St. Agnes, and St. Columb are in this basin.

St. Columb.—*Acres*, 120; population, 1113 in 1871; constant supply from moorland stream stored in reservoir holding 500,000 gallons; rateable value, 2548*l*.

Newquay.—Population, 1589; 3 public wells and 69 private; rateable value, 3375*l*. Only those at Mr. Treffry's, Mr. Prout's Hotel, Mr. George Bocking's, and Dr. Clarke's are fit for human consumption (Rivers Pollution Commission). Rainfall in 1879 was 34·97 inches.

Redruth.—*Acres*, 1168; population, 9335; main collecting water from adits driven into the granite, with dam; supply insufficient.

RIVER ALAN OR CANNEL (*CLXXXIX.*).

Length, 19 miles; area, 149, with tributaries, of which 27 square miles consist of part of the eastern granite boss, in which the tributary stream the *De Lank*, 7 miles in length, takes its source. The main stream is canalized up to Bodmin, which is close under the central Cornish watershed, though only 52 feet above the mean sea-level.

Bodmin.—*Acres*, 2785; population, 5061; 30 gallons per head is supplied by private Company to 3000 persons, by pumping engine worked by water and auxiliary steam power, lifting 7000 gallons per hour of water to a reservoir about 420 feet high, holding 250,000 gallons from Butterwell stream, a spring situated in an oak coppice wood, about 1½ miles from the town; 600 persons are separately supplied by County Justices in Lunatic Asylum; and remaining population are supplied by private wells. The Rivers Pollution Commission states the total solid impurity of the public supply to be 9·56; total hardness, 6·3, of which 5·6 was permanent; chlorine, 2·80. The water is off cultivated land, but is tolerably wholesome. The wells vary in hardness from 8·3 to 42·8, but only two are satisfactory, viz. St. Leonard's pump and Church Style Mouths well, giving respectively 19·36 and 14·72 of total solid impurity. Rate-

able value, 11,934*l.* Rainfall in 1879 varied from 49·06 to 52·15 at 338 feet above the sea. The mean annual rainfall at Castle Street, 315 feet above the sea, was, in

1850–9.	1860–9.	1870–9.
43·48	47·71	52·02

Padstow.—*Acres*, 180; population, 1849; rateable value, 3586*l.*; by private Act, 1860; constant supply from springs. The Rivers Pollution Commission reports the public well, 25 feet in the Devonian rock at Rosa's Lane, contains no less than 73·90 parts per 100,000 of solid impurity, with 28·7 of hardness.

Camelford and Wadebridge.—*Acres* in registration sub-district, 34,479, with a population of 5312. Rainfall in 1879, at 140 feet above the sea, 33·45 inches.

O.S. CATCHMENT BASIN CLXXXVIII.

Area, 8 square miles, the whole of which consists of Devonian rocks. This small basin is drained by streams passing to the sea on either side of Pentire Point.

O.S. CATCHMENT BASIN CLXXXVI.

Area, 108 square miles, of which 15 miles are of Devonian and 93 miles of Culm Measures. This basin has a very extensive sea frontage, ranging from Pentire Point, through Bude Bay, to Hartland Point, a distance of nearly 40 miles, with only an average width inland of 3 miles. One of the small streams intersecting Bude Bay is canalized.

O.S. CATCHMENT BASIN CLXXXV.

This small basin occupies 10 square miles, consisting entirely of Culm Measures, and from the southern coast to Bideford Bay for 12 miles, extending inland only about a mile.

RIVER TORRIDGE (CXXXVIII.).

Length, 47 miles; area, 336 square miles, with tributaries. This stream rises within 4 miles of the coast at Hartland

Point, and flows by Sheepwash to Hatherleigh, which forms the bottom of the loop of its U-shaped course, thence it flows north and north-west by Torrington, Bideford, and Appledore to the sea. The western margin of this basin is formed by the central Cornish watershed, which is deeply deflected southwards by this river and the *TAW*, rising in the Dartmoor Granite within 20 miles of the English Channel. The basin occupies a triangular area, the base being Bideford Bay, and the apex the meeting point of six basins on Dartmoor. The apex consists of 24 square miles of granite, the remaining 312 square miles of county consist of Culm Measures.

Bideford.—*Acres*, 3196; population, 6512; gathering ground, 500 acres; storage reservoir holds 15,000,000 gallons; water then flows into uncovered service reservoir holding 70,000 gallons; supply unfiltered; constant 100,000 gallons per day. Rainfall in 1879, at Horwood, 288 feet above the sea, 33·68 inches.

Hatherleigh.—[No information.]

Northam.—*Acres*, 4190; population, 4452; artesian well at Appledore, private wells, and private reservoir at Westward Ho, in the district; rateable value, 11,293*l.*; Local Government Act. Rainfall in 1879, at 173 feet above Ordnance Datum, 33·62 inches.

River Okement.

This tributary is 13 miles in length; it rises as two streams, the East and West *Okement*, at the extreme southern apex of the triangular basin of the *TORRIDGE*, uniting at an elevation of 493 feet above the sea, and falls into the *TORRIDGE* at Hatherleigh.

Okehampton.—*Acres*, 503; population, 1695; reservoir storing 300,000 gallons, from springs collected by earthenware pipes, supplying 50,000 gallons for domestic purposes, and 50,000 gallons for trade purposes, &c.; rateable value, 3232*l.*; Public Health Acts. Rainfall in 1879, at Oaklands, 521 feet above the sea, 44·96 inches.

Belstone and Exbourne are also drained by the *Okement*.

RIVER TAW (*CXXXIX.*).

Length, 26 miles; area, with that of its tributaries, 455 square miles; it rises in the Granite of Dartmoor, near the source of the *Okement*, the Granite occupying 9 square miles, thence it flows across the synclinally arranged Culm Measures, turning north-westward to Barnstaple. A little north of the bend, on the east bank, it receives the waters of the *Little Dart*, 12 miles in length, draining the Culm Measures.

River Mole.

Still further north is the infall of the *Mole*, 11 miles in length, whose feeders rise in the Devonian rocks, as do the sub-tributaries, the *Yeo* and the *Bray*. The Devonian rocks occupy 266 square miles in this basin, and are on the strike of the Exmoor country to the east, on the southern slopes of which rises the *EXE*, flowing into the English Channel.

The feeders of the *Mole* rise like the feeders of the *EXE*, and flow south, down the dip of the Devonian rocks and Culm Measures; but the waters of the *Mole*, on reaching the *TAW*, are carried northwards to the Bristol Channel. Had it not been for the upthrust of the Dartmoor Granite the *TORRIDGE* and the *TAW* would have probably flowed south, as do the streams respectively to the east and the west of them, the *TAMAR* and the *EXE;* and had this been so, it will be noticed that the central Cornish watershed, terminating east of Hartland Point, would have extended in an unbroken line across Bideford Bay to the North Devon and Central Somerset watershed, terminating west of Barnstaple.

Barnstaple.—*Acres*, 2000; population, 12,283; constant supply of 360,000 gallons, abstracted from River *Yeo*, 5 miles above the town, conveyed in open conduits and earthen pipes to reservoir. The water is clear, colourless, and palatable, but is derived from cultivated land; total solid impurity, 9·94; chlorine, 1·55; total hardness, 5·9, all of which is

permanent (Rivers Pollution Commission). The Commission states, the "cultivation of a non-calcareous soil does not add much soluble matter to the rain falling on it;" the average total solid impurity being 9·52, while the average total solid impurity of upland surface-water from non-calcareous formations is 6·32; so that only 3·20 is added by cultivation; rateable value, 27,046*l.* 15*s.*; 21 Vict. c. 20, and General Waterworks Act. Rainfall in 1879, at 31 feet above Ordnance Datum, 39·35 inches. At Arlington Court, 613 feet above the sea, 47·99 inches.

South Molton.—*Acres*, 6266; population, 3340; from Holywell, in the parish of North Molton, 5 miles distant; supply constant, stored in reservoir of 100,000 to 200,000 gallons; rateable value, 5376*l.* 12*s.* 6*d.*; South Molton Markets and Municipal Act, 1862, Local Government Acts. Mean annual rainfall at Castle Hill, at 300 feet above the sea:—

1860–9.	1870–9.	1880.
47·12	47·62	40·70

Population living on the South-Coast Streams, South of the Isle of Purbeck Axis and Exmoor (North Devon) Watershed.

Census of 1871.

Counties.	Population.	Density. Acres to Persons.	Proportion of Population in this Group.	Population, about.
Dorset	195,544	3·2	$\frac{1}{5}$	39,108
Devon	600,814	2·7	$\frac{19}{20}$	570,774
Cornwall	362,098	2·2	All	362,098
Somerset	463,412	2·2	$\frac{1}{20}$	23,170
Census of 1881.				
Dorset	190,979	3·2	$\frac{1}{5}$	38,195
Devon	604,397	2·7	$\frac{19}{20}$	574,178
Cornwall	329,484	2·6	All	329,484
Somerset	469,010	2·2	$\frac{1}{20}$	23,450

CHAPTER XX.

THE SEVERN BASIN. BRISTOL CHANNEL—SOUTH COAST GROUP.

Sea-coast—Baggy Point to Aust Cliff.

THE basin of the *SEVERN* is bounded west by the central mountains of Wales, north by the watersheds of the *DEE* and the *WEAVER*, east by the watersheds of the *TRENT*, the *THAMES*, and the Hampshire and Wilts basin streams, south by the West Somerset and North Devon watersheds.

This large area forms three natural groups of basins, eleven of which, including the Bristol *AVON*, drain 2160 square miles, and fall into the Bristol Channel south of the outfall of the *SEVERN*. The drainage area of the *SEVERN*, including its tributary the *AVON*, is 4350 square miles. And eight basins, including the *WYE*, draining 2683 square miles, flow into the Bristol Channel north of the outfall of the *SEVERN*.

O.S. CATCHMENT BASIN CXXXVII.

Occupies 47 square miles, all of which consist of Devonian rocks; it includes the coasts of the northern part of Barnstaple or Bideford Bay, North Bay, and the coast between Bull Point and Lynmouth, in which Ilfracombe is situated, in all 26 miles in extent, but the depth inland is only 2 miles. The southern margin is formed by the North Devon watershed, which traverses an anticlinal running with the strike of rocks, which causes these rocks to plunge north under the Carboniferous Limestone of the Mendips, which replaces the Culm Measures of the southern side of the synclinal fold.

ILFRACOMBE.—*Acres*, 5583; population, 6043. Surface

waters on hill-sides, two springs, and a small stream at Slade Valley, collected in a reservoir of 4 acres, formed by embankment across valley, holding 262,260 gallons; supply 100,000 gallons, or 20 gallons a head; rateable value, 23,500*l.*; Public Health Acts; rainfall in 1879, 31·87 inches; total solid impurity, 12·48; chlorine, 2·05; total hardness, 6·9, all of which was permanent, clear and colourless (Rivers Pollution Commission). This amount of solid impurity and hardness is above the average of upland surface waters from those ancient rocks generally.

Rainfall at the Ilfracombe Hotel, 34 feet above the Sea.

1878.	1879.	1880.
29·83	31·87	33·19

EAST LYNN (CXL.).

Length, 11 miles; area, 41 square miles, all of which consist of Devonian rocks, forming the northern slope of Exmoor; its position is similar to the last basin described.

Lynton. — *Acres*, 7193; population, 1212; constant supply of 30,000 gallons; filtered, stored in reservoir, from the *EAST LYNN*, which also supplies Lynmouth. The total solid impurity is 6·36; chlorine, 1·25; hardness, all permanent, 2·5. Rainfall in 1880, 44·94 inches at Lee Abbey.

Great Torrington. — *Acres*, 3456; population, 3445; constant supply from reservoir 1½ mile from town, impounding a stream belonging to *Torrington Water Company (Limited)*; rateable value, 8557*l.*

Rainfall in 1879, at Langtree Wick, 451 feet above the sea, 43·76 inches; in 1880, 44·94 inches.

O.S. CATCHMENT BASIN CXLI.

Area, 29 square miles; forms the north-eastern corner of Exmoor; the whole of the basin consists of Devonian rocks,

with some Triassic deposits filling in the bottoms of the valleys, the latter occupying about 5 square miles.

MINEHEAD.—[No information.]

O.S. CATCHMENT BASIN CXLII.

Area of these streams is 24 square miles, of which 20 are Devonian and 4 Triassic rocks. This basin also has its southern margin bounded by the Central Somerset watershed.

O.S. CATCHMENT BASIN CXLIII.

Area, 82 square miles, of which 57 are Devonian, 13 Triassic, and 12 Liassic rocks. In this basin the Lias is again reached, which formation occupies no less than 1359 square miles in the *SEVERN* group. The Devonian rocks occur in two areas in this basin; a deep valley between the hills ranging from Exmoor to Taunton is filled at the bottom with Triassic rocks, and separates the Devonian of the Quantocks from the main mass, the Quantocks forming an island, surrounded with Triassic deposits. A transverse watershed, commencing above the head waters of the *Tone*, draining the Vale of Taunton, crosses the valley, and, ascending and passing over the Quantocks, separates this basin from that of the *PARRET*, reaching the sea near the mouth of the latter river. Watchet is in this basin.

RIVER PARRET (CXLVIII.).

Length, 36 miles; area, with that of tributaries, 562 square miles. The southern margin is formed by the Central Somerset watershed, separating it from the basins of the *EXE*, *OTTER*, *AXE*, and *FROME*. Its eastern limit is the diagonal watershed separating it from the *STOUR* draining into the Hampshire basin. Devonian rocks and Culm Measures occupy 60 square miles at the north-western corner of the basin, including the termination of the Exmoor range of hills overlooking the Vale of Taunton and the Quantocks, rising above the New Red plain. The Sand-

stones of the New Red Series occupy 34 miles, and the Marls 94, while the Lias extends over the central and southern area for 300 square miles, the Oolites of Blackmoor between Crewkerne, Yeovil, and Sherborne occupying 62 miles. The Upper Greensand, 10 square miles, resting on the Red Marls and the Lias between Wellington and Ilminster, is capped by 2 miles of Chalk and Chalk Marl at Chard, which is situated on the watershed between the *PARRET* and the *AXE*. Immediately east of Chard, the watershed traverses the Lias for a distance of a mile between two hills capped by Cretaceous outliers; the London and South-Western Railway to Exeter is carried through this depression. Westward of Chard, after traversing the ridge of Greensand capping the Red Marls, the watershed again descends, and crosses a depression lying between the valley of the *Culm* and the Vale of Taunton; through this col the Great Western Railway to Exeter reaches the *EXE* basin, between Wellington and Cullompton. This depression had also previously been made available for carrying the canal connecting the *Culm* with the River *Tone*, linking the English with the Bristol Channel.

Crewkerne.—Rainfall in 1879, at Bincombe House, 250 feet above the sea, 38·17 inches; in 1880, 36·33 inches.

South Petherton.—*Acres*, registration sub-district, 2385; population, 3742. Rainfall in 1879, 150 feet above the sea, 29·76; in 1880, 30·88 inches.

Chard.—Population, 2411; reservoir, constant supply from springs; rateable value, 4978*l.* 6*s.* 11*d.*; works under Guardians, by Poor Law Act; those under the Council, under the Municipal Act. Rainfall in 1879, at Cricket St. Thomas, 400 feet above the sea, 41·23 inches; in 1880, 38·13 inches.

Bridgwater.—*Acres*, 144; population, 12,024; western side of the *PARRET*, town built on gravel, eastern side on alluvium, supplied by dangerous shallow wells; works now being carried out for supply from Quantock Hills under Bridgwater Corporation Water Act, 1877; rateable value, 48,399*l.*

The Tributary *Tone* on the west bank is 33 miles long, rising in the Devonian at Wellington. It is 259 feet above the mean sea-level, with a rainfall of 33·7. At Taunton it flows over the Red Marls through the Vale of Taunton (the rainfall of the latter place is 30·7), thence over the Lias to the *PARRET*, which it enters at right angles to the direction of the course of the latter between Bridgwater and Langport. Of the area drained by this tributary not more than 12 square miles consist of permeable rocks, the Devonian, Red Marls, and Lias all throwing off rainfall in floods.

Wellington.—*Acres*, 5195; population, 6360; private and public wells only; rateable value, 24,433*l*. Rainfall in 1879, at Sunnyside, 32·31 inches; in 1880, 32·34 inches.

Wiveliscombe.—*Acres*, 84; population, 1624; 18 gallons per head from reservoir, collecting springs, and an open stream (at present *diverted* by owner of land); rateable value, 271*0l*.; under Public Health Act, 1848.

Taunton.—*Acres*, 1245; population, 16,611; supply 120,000 gallons from Greensands of Blackdown Hills. The Rivers Pollution Commission considers it surface water from cultivated land. Total solid impurity, 8·58, 1·50; total hardness, all permanent, 2·6; organic impurity high. Rainfall in 1879, 27·77 inches; in 1880, 30·85 inches.

River Isle.

This stream is 9 miles long, and also falls in on the west bank; it drains entirely a Liassic country. Its head springs are crossed by a canal at a height of 267 feet above the sea, running from the *Tone* by Ilminster to Chard.

Ilminster had 2431 inhabitants in 1871; supply from public springs and wells in Lias. Rivers Pollution Commission states the total solid impurity was 58·12; total hardness, 43·5, of which 17·4 was permanent. The Middle Lias at Ilminster is stated by Mr. Bristow, F.R.S.,* to be 158 feet thick.

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* Memoirs of the Geological Survey, Bristol Coalfield.

River Yeo.

This tributary of the *PARRET* is 15 miles in length, rises on the Oolitic hills under the diagonal watershed above Sherborne, flows over the Lias, and falls into the *PARRET* on the east bank at Langport.

SHERBORNE.—Mean annual rainfall:—

1860–9.	1870–9.	1880.
42·10	47·26	38·93

Thickness of "Midford Sands," 250 feet; Inferior Oolite, 90 to 100 feet.

ILCHESTER.—*Acres* in registration sub-district, 10,844, with a population of 2093.

YEOVIL.—Population, 8480; reservoir giving constant supply from a spring at Halywell, Dorset, 9 miles distant; rateable value, 25,925*l.*; Yeovil Improvement Act, 1870. Rainfall in 1879, at West Coker, 236 feet above Ordnance Datum, 35·19 inches; in 1880, 34·67 inches.

RIVER CARY (CXLVII.).

This is a tributary of the *PARRET*, falling into the right bank in the tidal portion of the river; but it is considered a distinct basin by the Ordnance Survey, with an area of 80 square miles, all of which consist of impermeable strata, 70 being Keuper Marls, and 10 Lias.

SOMERTON.—Population, 2302 in 1871; supplied with water from wells in the Lias and streams; analyzed by Rivers Pollution Commission, and nearly all found dangerously polluted; 11 wells ranged from 54·08 total solid impurity, with 38·3 total hardness, to 199·20 total solid impurity and 75·7 of hardness. The total impurity of the stream was 40·40, with total hardness of 29·1; artesian well section at the west end of the town passed through 120 feet Lias, without penetrating it.

Castle Cary is in this basin, with a district population of 5414: the thickness of the Middle Lias, 50 feet; Midford Sands, 165 feet; Inferior Oolite, 45 feet (Mr. Bristow, in the Geological Survey Memoirs).

RIVER BRUE (CXLVI.).

Length, 29 miles; area, 197 square miles, of which 35 are Keuper Marls, 107 Lias, 50 Oolite, 4 Upper Greensand, and 1 Chalk. The stream rises in the latter formation under the diagonal watershed, and flows west over higher and higher beds; the greater portion of it is impermeable.

Bruton is situated near the base of the Oolites; population in the registration sub-district, 3191. The thickness of the Middle Lias (Scorle Hill) is 21 feet; Midford Sands, 66 feet; Inferior Oolite, 55 feet; and Fuller's Earth, 174 feet.

Glastonbury.—*Acres*, 7102; population, 3719; reservoir storing springs from Wellhouse Lane and Edmund Hill springs; supply about 25,000 gallons; rateable value, 19,447*l.*; under 21 & 22 Vict. c. 98.

At Glastonbury Tor, the Dolomitic Conglomerate and Red Marl is given at 400 feet, the Rhætics at 40 feet, the Lower and Middle Lias at 300 feet, the Upper Lias at 14 feet, and the Midford Sands at 190 feet.

Street.—*Acres*, 2828; population, 2157 in 1871; private wells; supply 35,000 gallons constant; rateable value, 9404*l.* 7*s.* 6*d.* Rainfall in 1879, at Street, 70 feet above the sea, 34·27 inches; in 1880, 33·46 inches.

Burnham.—*Acres*, 632; population, 1921; private wells; rateable value, 6875*l.* Rainfall in 1879, 18 feet above Ordnance Datum, 33·73 inches; in 1880, 30·53 inches.

Shepton Mallet.—*Acres*, 3600; population, 5322; springs in the Mendips, 1½ mile distant; supply 108,000 to 288,000 gallons, chiefly for brewing purposes; rateable value, 17,330*l.*; Shepton Mallet Water Company's Act, 22 & 23 Vict., 1859, and 39 & 40 Vict., 1876. The Rhætic beds here reach a thickness of 43 feet.

North of the River *Yeo* the Lower Fuller's Earth thins out, the beds rising steadily northward. At Patsons Hill the Inferior Oolite has disappeared, and sands (g 4) 270 feet thick rest on 140 feet of ferruginous micaceous sands, with

beds of concretionary limestone in the upper part of the series (Marlstone), resting on at least 150 feet of Lias, Marl, and Clay (Lower Lias). This section is continued in Sheet 15.

The same thickness is continued at Ridge Barn Hill, on the River *Brue* at Wickchampflower Church and at Castle Cary; at Lamyat Beacon, the Lower Lias is represented as 440 feet in thickness, and the distance between the base of the Lower Fuller's Earth and the Lower Lias as 660 feet, the hill being about 800 feet, and the top of the Keuper Marls being at or near the sea-level, rising for a short distance with the dip, and then again disappearing; and the Fuller's Earth series again forms much of the series, until they thin out against the Carboniferous Limestone of Downhead Hill. Sir Henry De la Beche represents the Inferior Oolite as overlapping the Lias Sands, Marlstone, and Lower Lias, and Red Marls, all of which are much attenuated, and rest on the Dolomitic Conglomerate, filling in the hollows of the Limestone, which is at least 1500 feet thick, resting on 450 feet of Argillaceous Shale, and 2700 feet of Old Red Sandstone, in Shale, with Marl and Conglomerates, with quartz pebble.

RIVER AXE (CXLV.).

Length, 10 miles; area, 101 square miles, of which Carboniferous Limestone occupies 33, Triassic Marls, 64; Lias, 2; and Oolites, 2; it is bounded east by the Bristol *AVON* basin. It rises in the Carboniferous Limestone of the southern slopes of the Mendips, flows past Wells, through a broad alluvial tract to the sea, south of Weston-super-Mare; the alluvium overlying Triassic Marls.

Wells.—*Acres*, 612; population, 4633; springs and wells stored in reservoir yield 150,000 gallons constant; Waterworks Company; rateable value, 11,992*l.* 5*s.* 8*d.*

Axbridge.—*Acres* in the registration sub-district, 18,297, with a population of 5704.

RIVER YEO (CXXVI.).

Area, 106 square miles, of which 5 are occupied by Carboniferous Limestone, 3 by Carboniferous rocks, and 98 by Trias, much obscured by alluvium.

Weston-super-Mare.—*Acres*, 1597; population, 12,282; rateable value, 57,015*l.* 7*s.* 3*d.* Waterworks Company give constant supply from a spring in the Mountain Limestone. It is intensely hard, and contains a large quantity of common salt. The Rivers Pollution Commission states the temperature of this spring to be 13·8. Total solid impurity, 98·50; chlorine, 32·00 (!); hardness, 48·5, of which 29·5 was permanent. The average hardness of thirteen samples of water from the Carboniferous Limestone, analyzed by the Commission, was 19·8, or, omitting the Weston-super-Mare sample, 17·4, the latter average including the so-called mineral springs at Buxton.

East Brent.—Archdeacon Denison's reservoir, Axbridge.

Midsomer Norton.—*Acres*, 3722; population, 4419; wells; rateable value, 15,501*l.*

RIVER AVON (CXXVII.).

Length, 62 miles; area, with its tributaries, 891 square miles. It is sometimes called the *WEST AVON*, to distinguish it from the Hampshire *EAST AVON*, flowing through Salisbury, rising near some of its feeders, on the opposite side of the diagonal watershed, and sometimes the *LOWER AVON*, to distinguish it from the *UPPER*, or Warwickshire, *AVON*, falling into the *SEVERN* at Tewkesbury.

The Bristol *AVON* basin is bounded, south by the Mendips, east by the Cretaceous escarpment forming the margin of the Hampshire and *THAMES* basin, north-east by a portion of the diagonal watershed ranging across the Oolitic rocks, the *AVON* rising in them on one side of the watershed and the *THAMES* head on the other, the elevation of the summit level, 354 to 397 feet. The county boundary ranges along

the course of the *AVON* for a few miles up to its source, then crosses the watershed into the *THAMES* basin.

Of the 891 square miles of area, 9 consist of Carboniferous Limestone, 17 of later Carboniferous rocks, 140 of Triassic Marls, 109 of Lias, 560 of Oolites, 43 of Greensand and Gault, and 13 of Chalk. Following the river from its outfall, it passes across the Red Marls, and through the magnificent gorge in the Carboniferous Limestone at Clifton, to Bristol, 35 feet above Ordnance Datum, with a rainfall of 33·7; thence across Lias and Trias, overlying the Bristol Coalfield to Bath, with an elevation of 63 feet, and a rainfall of 30·5. Here commences the canal ascending the river, and dividing into two branches, both of which pass into the *THAMES* basin. From Bath to its source the stream flows over the Oolites, passing Bradford and Trowbridge; it attains a height of 122 feet at Melksham, 152 feet at Chippenham, with a rainfall of 28·1 inches, thence it flows north by Malmesbury and Tetbury to its sources.

North of the Coalfield, at Priest's Barrow, the following sequence is given by Sir Henry De la Beche and Prof. Ramsay:—Inferior Oolite 20 feet, Sands 30 feet, and Lower Lias 200; the upper bed of the Lias here thins out, and the Lower Lias is much attenuated, but increases in thickness northwards, as do the Red Marls, which here reach 360 feet, resting on Coal Measures, and further south on the Dolomitic Conglomerate.

At the Inferior Oolite outliers further north at Stantonbury Hill Camp the Lower Lias has increased to 290 feet, and the Sands to 50 feet. Still further north, on the northern slope of the River *AVON* at Jay Hill, the Marlstone makes a re-appearance, the sequence being:—Inferior Oolite 20 feet, Sands 50 feet, Marlstone 80 feet, and Lias, Limestone, and Marl 120 feet (+).

Tetbury (Gloucester).—*Acres*, 80; population, 2419.

Malmesbury (Wilts).—*Acres*, 325; population, 3133; Waterworks Co.; two streams and private wells; good supply after great floods; rateable value, 4762*l*.

Chippenham.—*Acres*, 287; population, 4495; 90,000 gallons pumped into a reservoir out of a well; rateable value, 12,038*l*.

Calne.—*Acres*, 410; population, 3406; three pump wells and three dipping wells only; rateable value, 8915*l*. Rainfall in 1879, 39·12 inches; at Compton Bassett, 400 feet above the sea, 36·71 inches.

Devizes.—*Acres*, 917; population, 6645; well about 4½ miles off in the Chalk, pumped to reservoir by steam; rateable value, 22,395*l*. Rainfall in 1879, at Bishop's Canning, 446 feet above Ordnance Datum, 35·67 inches.

Trowbridge.—*Acres*, 1794; population, 11,041; constant supply of 55,000 gallons a day from Biss Springs, out of the Chalk at Upton Scudamore, 6 miles distant. The Company first sank a well in the Lias 160 feet deep, with 40 feet bore of 18 inches diameter at the bottom. In sinking the shaft a salt spring was met with, which was stopped out, but salt water came in 20 feet from the surface, and the Rivers Pollution Commission found the water to yield 6 lbs. of common salt to the 1000 gallons, instead of the usual proportion of 3 oz. The temperature was 11·1 C.; total solid impurity, 144·34; chlorine, 36·70; total hardness, 57·1, of which 29·7 was permanent; rateable value, 23,000*l*.; 36 & 37 Vict., 1873; the Trowbridge Water Act. Rainfall in 1879, 140 feet above Ordnance Datum, 33·40 inches.

Bradford-on-Avon.—*Acres*, 2010; population, 16,133; waterworks are projected; rateable value, 11,000*l*.

Bath.—*Acres*, 3745; population, 51,790; three Corporation reservoirs 4 miles distant; storing springs from Inferior Oolite sand; given 25 gallons per head to 30,000 inhabitants; under Bath Acts, 1846, 1851, 1870, and 1876; rateable value, 264,756*l*. In addition, there are eighteen private companies supplying about 13,000 inhabitants. The best water examined by the Rivers Pollution Commission is that supplied to the Bath Wick district from Beacon springs; the next is that supplied to the Abbey district from Sham Castle springs. The water in the Belvedere district from Beacon Hill

spring, and the water supplied to Lincombe and Wincombe districts from springs under Beechen Cliff, have been heavily contaminated with organic impurity. Rainfall in 1879, at Royal Literary Institute, 75 feet above Ordnance Datum, 35·62 inches; in 1880, 29·91 inches.

	Total Solid Impurity.	Chlorine.	Hardness.			Remarks.
			Temp.	Perm.	Total.	
Spring at Batheaston	31·60	1·66	17·5	6·7	24·2	Polluted.
Beacon Springs	20·40	1·45	10·7	5·6	16·3	„
Sham Castle Springs ..	30·70	1·65	18·1	7·0	25·1	„
Monkswood Spring, *Lias*	35·18	1·55	23·1	6·0	29·1	Pure.
Hampton Down Spring. *Oolites*	22·40	1·30	15·1	3·5	18·6	„
Eyford Spring, *Oolites*..	30·76	1·46	21·8	3·4	27·2	„
Hetling Thermal Spring	240·52	26·50	22·0	82·8	104·8	Clear.
King's Bath Thermal Spring	245·40	26·67	22·0	82·8	104·8	„

The thermal springs resemble the cold-water springs of the neighbourhood in containing a large amount of organic matter; their temperature was 44·4 and 42·2 C. respectively; that of the cold springs at Hampton Downs was 8·1 C.

The Royal Commissioners point out that the thermal springs of Bath, like the cold water, contain a large amount of organic impurity. These waters have been tapped in a well at Kingsmead Street, at the junction of the Keuper and Penarth beds. They were believed by William Smith, and later by Sir Charles Lyell, to rise from subjacent Carboniferous rocks at a great depth. They give off, according to Dr. Daubeny, a daily quantity of 250 cubic feet of nitrogen gas, as well as carbonic acid gas. Lithium, strontium, and copper have been determined in their waters by Dr. Roscoe, and various salts were found by Messrs. G. Merck and Galloway in an imperial gallon.

The Geological Survey Memoir on the Bristol Coalfield gives the following thickness at Bath: Rhætic Beds, 39 feet;

Lower and Middle Lias, 170–260 feet; Midford Sand, 100 feet; Inferior Oolite, 30 feet; Fuller's Earth, 150 feet; Great Oolite, 60 feet. At Bedminster the Dolomitic Conglomerate and Red Marls are given at 100 feet. At Dundry Hill the Red Marl is 170 feet; the Rhætic beds, 30 feet; Lias, 450 feet; Midford Sands, 2 feet; Inferior Oolite, 41 to 85 feet.

The Great Oolite, at Bath, consists of the following series :—

		Feet.
A. Upper Rags ..	1. Coarse shelly limestone ..	20 to 55
	2. Rather fine grained oolite ..	
	3. Tough brown limestone ..	
B. Fine freestone	.. ..	10 to 30
C. Lower Rags ..	Coarse shelly limestone	10 to 40

The good Freestone is very soft when first obtained, containing much moisture, amounting sometimes, it is said, to 1 gallon of water per cubic foot.

The *Bradford Clay*, a local thickening of the clayey beds of the overlying Forest Marble, reaches its greatest thickness at Farleigh, where it is 40 to 60 feet. The Forest Marble around Bath is 100 feet thick; in the Cotswolds not more than 50.

The *Cornbrash* rubbly limestones reach a thickness of more than 40 feet, and are overlaid by 300 to 400 feet of Oxford Clay.

The *Coral Rag* at Longleat Park, near Warminster, underlies the Kimmeridge Clay, which reaches a thickness of 65 feet at Maiden Bradley.

In the outcrop of the Oolitic rocks, ranging between Crewkerne, through Bath, to Wootton-under-Edge, described by Mr. H. B. Woodward, the Coral Rag, when present, is water-bearing; the Oxford Clay forms the impermeable layer, as do also the Cornbrash and the upper sandy beds of the Forest Marble, which are held up by the clayey beds beneath.

The outcrop of the Cornbrash, between Witham Friary,

South Brewham, and Hardway to Wincanton, is marked by a line of villages, due, as pointed out by Professor Buckman, not only to the fertility of the soil of the Cornbrash, but to the fact that this porous rock, resting on the impervious Forest Marble, is a collecting ground for water, which is kept up by the latter rock.

Professor Judd gives a very valuable series of comparative vertical sections in the Geological Survey Memoir on the county of Rutland, to illustrate the variation in thickness and mineral characters of the several members of the Lower Oolites across the midland counties from Bath to South Yorkshire; from which it will be seen that, at Bath, the beds lying between the Cornbrash and Midford Sands (inclusive) reach a thickness of 575 feet, while at Towcester, in the Bedford *OUSE* Valley, 82 miles distant, they are reduced to 125 feet, or a north-easterly attenuation of 450 feet, or 5 feet per mile traversed. Between Towcester and South Yorkshire the thickness locally increases in Mid Lincolnshire, where the great development of the Lincolnshire Limestone (Inferior Oolite) brings the thickness steadily up to 240 feet near Lincoln. The increase in thickness between Towcester and Lincoln is 115 feet in 77 miles, or $1\frac{1}{2}$ foot per mile traversed. From this minor roll of maximum thickness, the beds again thin northwards to only 30 feet in South Yorkshire, or 210 feet in 35 miles, or 6 feet per mile traversed. In the South Yorkshire section the representatives of three-fourths of the upper part of the column are absent, including all the beds down to the base of the Fuller's Earth, 30 feet of Lincolnshire Oolite and underlying sands being alone left to represent the Inferior Oolite and Midford Sands of Bath. Disregarding the local thickening of the Inferior Oolite Freestones at Stroud and Cheltenham, the total attenuation of the Lower Oolites between Bath and South Yorkshire is 545 feet in 196 miles, or $2\frac{3}{4}$ feet per mile traversed in the whole distance. Diagramatically, the Lower Oolitic escarpment might be represented by a wedge, the thick end resting on Bath and the apex on South Yorkshire.

At Bath, Professor Judd gives the details as follows:—

Formation.	Lithological Character and Thicknesses.		
	Shales and Clays.	Sand-stones.	Lime-stones.
Cornbrash	3	..	12
Forest Marble	18	50	30
Bradford Clay	60	..	..
Great Oolite	..	..	125
Fuller's Earth	125	..	20
Inferior Oolite	..	..	66
Midford Sands	..	5	63
	206*	55	316

Clevedon.—*Acres*, 3000; population, 4869; from a spring from Limestone rock; two reservoirs supply 128,000 to 160,000 gallons; constant; rateable value, 26,108*l.* 14*s.* 6*d.*; Companies Act, 1862.

Bristol.—Population, 182,552 in 1871, 206,503 in 1881; rateable value, 804,333*l.*; works carried out under Bristol Waterworks Act, 1862; Amendment Acts, 1865 and 1872.

The Bristol gravitation works for bringing water from the Mendips and other springs in Somersetshire were completed in 1851; the supply was to have been 4,000,000 gallons a day, but that in dry years this was not practicable was recognized in 1860, and in 1862 the Company obtained an Act of Parliament enabling them to construct additional reservoirs; but, before these were completed, the absence of rain in the winters of 1861, 1862, and 1863 so seriously affected the yield of the springs, that early in 1864 recourse had to be taken to all available springs and other sources round Bristol, and notwithstanding the temporary pumping, the supplies were exhausted, and the springs did not yield more than 350,000 gallons per day. A permanent pumping scheme for a supplementary supply in dry years, from springs 8 miles from Bristol, was therefore carried out, and an additional store reservoir completed, raising the total

* Or 206 feet of impermeable material, and 371 feet of permeable.

storage, exclusive of mill compensation, to 350,000 gallons, or 88 days' supply at 4,000,000 gallons per day.

The springs at Chewton Mendip on the side of the Mendips are in Triassic (Dolomitic?) Conglomerates and from springs in the Carboniferous Limestone. The water pumped from wells at Chelvey are sunk in the New Red Sandstone, 200 yards from any inhabited place; 2 of them 40 feet deep, and a third 196 feet. The two storage reservoirs are at Barrow, 4 miles distant; cover 66½ acres, holding 332 millions, and the five service reservoirs hold 11,500,000 gallons.

The Rivers Pollution Commission gives the total solid impurity of the city supply as 27·24; chlorine, 1·30; total hardness, 24·8, of which only 4·6 were permanent; private and public wells supply much water. The rainfall in 1879, at Small Street, Bristol, 49 feet above the sea, was 35·11 inches.

Horfield (Gloucestershire).—*Acres*, 218; population, 2195 in 1871, 5740 in 1881; private wells; certain houses from main of *Bristol Waterworks;* rateable value, 1076*l.*

St. George (Clifton).—*Acres*, 1800; population, 16,209 in 1871, 26,394 in 1881; private wells and from *Bristol Waterworks* mains; rateable value, 35,560*l.* Mean annual rainfall:—

1860–9.	1870–9.	1880.
34·09	36·36	37·37

Tributaries, south bank, the *Chew*, 10 miles long, rising on the northern slope of the Mendips, with rainfall of 35·0 at its head waters.

A *stream* between Freshford and Radstock, which is canalized, with a rainfall of 39·4 at its head waters.

River Frome, 19 miles in length, rises on the Oolites on the extreme south-eastern margin of the basin. Flowing past Frome, it falls into the main stream at Bradford.

A *stream*, falling in between Bradford and Melksham, rises in the Cretaceous escarpment bounding Salisbury Plain; the Avon Canal follows the stream for a few miles and then divides, one branch being carried east by Devizes, where it is

433 feet above the sea, crossing two watersheds into the *Kennet* Valley above Hungerford, at 463, the other running parallel to the *AVON*, sending off a branch to Chippenham, 190 feet above the sea, and another to Calne at 228 feet, thence crossing the *THAMES* watershed above Swindon at 394 feet.

Radstock (Somerset).—*Acres*, 1000; population, 3092; private wells; rateable value, 9233*l*. Rainfall at Downside, 592 feet above the sea, in 1879, 50·41 inches; in 1880, 43·40 inches.

Frome.—*Acres*, 705; population, 9376; deep well projected; rateable value, 24,956*l*. Rainfall in 1879, at Mells Rectory, 344 feet above Ordnance Datum, 42·98 inches; in 1880, 39·90 inches.

The following thicknesses of strata in this district are given in the Memoirs of the Geological Survey, Geology of East Somerset and the Bristol Coalfields, chiefly measured by Mr. H. W. Bristow, F.R.S.:—

Dolomitic Conglomerates (at Radstock), 19 feet; Red Marl and Sandstone, 167 feet; Lias, 54 to 90 feet; Inferior Oolite, 35 feet.

Population in the Bristol Channel Group of the Severn Basin in the Census of 1871.

Counties.	Population.	Density. Acres to Persons.	Proportion of Population, probably living in this Group.	Population, about.
Devon	600,814	2·7	$\frac{1}{20}$	30,040
Somerset	463,412	2·2	$\frac{19}{20}$	440,242
Wilts	257,202	3·4	$\frac{1}{4}$	64,300
Gloucester	534,320	1·5	$\frac{1}{16}$	33,395
In the Census of 1881.				
Devon	604,397	2·7	$\frac{1}{20}$	30,219
Somerset	469,010	2·2	$\frac{19}{20}$	435,560
Wilts	258,967	3·2	$\frac{1}{4}$	64,741
Gloucester	572,480	1·4	$\frac{1}{16}$	35,780

CHAPTER XXI.

EAST BANK OF THE LOWER AND CENTRAL SEVERN BASIN.

The River *SEVERN* is 158 miles long, and contains an area of 4375 square miles, excluding the Lower *AVON* and the *WYE*. This area is so large, and the number of its tributaries so numerous, that it will be found advantageous to separate this basin into three portions: the Lower *SEVERN*, extending from the Bristol Channel to the infall of the Upper *AVON;* the Mid or Central *SEVERN*, up to the infall of the *Vyrnwy*, above Shrewsbury; the Upper *SEVERN* extending from this infall to the source. Following the description of the *THAMES*, it will also be found convenient to take the east bank and its tributaries first, and then the west or right bank.

Lower *SEVERN BASIN.*

The Lower *SEVERN*, from the Bristol *AVON* and the *WYE* up to Tewkesbury, drains about 620 square miles, of which about 415 square miles are on the left bank. Silurians occupy 16 square miles, Old Red Sandstones 3 miles, and Carboniferous Limestone about 5 miles; west of the Oolitic escarpment, at Wootton-under-Edge, these ancient rocks are surrounded by about 23 square miles of Red Marls, and more or less covered with alluvium, occupying the Vale of Berkeley; the remaining 368 square miles consist of Lias and Oolites. The former has an area of 278 square miles, the latter occupying 90 of the 94 square miles occupied by this formation in the *SEVERN* Basin, the remaining 4 miles being in the sub-basin of the Upper *AVON.*

The River *SEVERN* was surveyed in 1849 by Captain Beechey, F.R.S., by order of the Lords of the Admiralty.

Above Lidney, low water at spring tides was as low as at neaps, which is due to the waves throwing more water into the river than can escape at neap tides. The maximum height of the springs is between Framilode and Rosemary. Comparing the velocities of the tidal wave and bore of the *SEVERN* at spring tide, the latter is seen to fluctuate in the inverse ratio of the velocity of the tidal wave. The *Bore*, or foot of the wave, is caused by the *fall* of the *SEVERN* increasing as it approaches the tide-way, which is obstructed by shoals and banks, causing the tidal wave to assume a head too great for its depth, which "topples over in the characteristic form of the bore."*

River Severn: Summer Low-water Level, and High Floods Level of December 4th, 1849, Compared. From Captain Beechey's Admiralty Survey.

Datum of Heights is Ordnance Datum.	Summer Low Water.				Flood Level.		
	Mean Fall of River Bed per Mile.	Height on Gauge at Low Water.	Fall per Mile.	Area, Square Feet.	Height on Gauge at Low Water.	Fall per Mile.	Area, Square Feet.
	Feet.						
Sharpness (Below O.D.)	1·64	2·79	0·74	4176	1·00	..	7596
Framilode (Above O.D.)	0·85	15·00	1·31	3600	19·16	1·21	5467
Stonebench	0·36	16·92	0·227	632	25·00	0·69	2582
Lower Parting (Gloucester)	..	17·15	0·064	783	29·08	1·135	2328
Diglis Lock (Gloucester)	0·392	24·84	0·445	255	40·16	0·68	2248

After passing Framilode, the velocity of the tide-wave is reduced by sharp turns, sand-banks, and other obstacles, up to Rosemary Point, to 10 miles an hour, or half the rate at which it travels up to Sharpness, while the bore between Beachley and Sharpness travels at 870 feet per minute, and at 550 feet per minute at Framilode and Rosemary Point, above which it increases to 1300 feet per minute; the ascent of the low-water surface is only 0·12 of a foot per mile; the bore above Haw Bridge, is reduced to 713 feet per minute, and

* Mr. Nathaniel Beardmore, in 'Hydraulic Tables.' London: Weale, 1852.

ceases at Upton Bridge. When the river is low, in dry weather, the dry sand-banks offer great resistance to the bore, and it does not attain a greater velocity than 4 miles an hour; but, under the influence of freshes, when the water is raised, it rolls in at the rate of 10 miles an hour, in opposition to the stream flowing out at 4 miles an hour. At the Partings (Gloucester) it is then scarcely perceptible.

Spring tides at Stonebench travelled at the flow 400 feet per minute, with a sectional area of 2150 square feet; at the average ebb, 275 feet per minute, with a sectional area of 1700 square feet. According to a Table given by Mr. Beardmore,* the *SEVERN* at Stonebench drains 3900 square miles, and has an ordinary summer discharge of 33,111 cubic feet per minute, equal to 8·49 cubic feet per minute per square mile of drainage, representing an annual rainfall of only 1·98 inch, which is about the same ratio as the *NEN* at Peterborough. In the flood of the 4th of December, 1849, of which some details are given above, Captain Beechey states that the volume run off below Gloucester amounted to 751,245 cubic feet per minute, or 193·12 cubic feet per square mile of drainage, representing one-eighth of an inch of rainfall in 24 hours, or 6,739,000,000 gallons off a drainage area of 3890 square miles.

In 1841 the River *SEVERN* Commissioners applied to Parliament for powers to carry out a plan to improve 42 miles of the river, recommended by the late Mr. (afterwards Sir William) Cubitt, who proposed to construct five solid weirs, placed obliquely across the river, with a lock at the side of the weir for navigation purposes; the object of the works being to give a clear depth of 6 feet throughout that length of the river. He contended that weirs so placed would increase the breadth of the stream two-and-a-half times, over which the flood-waters would pass in a thin film, and would not be obstructed; and he further contested, that when the flood-level overtopped the weir, and the

* 'Hydraulic Tables,' 1852.

current resumed its normal course parallel to the line of the stream, the only obstruction offered by the weir was the cross-section of the weir itself in a line at right angles to the stream.

The late Mr. James Walker, opposing the scheme for the Gloucester and Berkeley Canal Company, objected to the lowest weir, preferring the lower 10 miles to be treated as a free stream, while in the upper 12 miles he proposed to erect movable weirs; and he maintained that fixed weirs offered an obstruction to the flood-water equal to the breadth of the river, multiplied by the height of the weir, whether fixed or placed obliquely; and he considered the construction of solid weirs would lead to the deposit of silt behind them, and the increase of floods.

The Parliamentary Committee, however, sanctioned four of Mr. Cubitt's proposed locks, which were carried out by Mr. Leader Williams, the engineer to the Severn Commission. The lower weir, however, was not sanctioned, and the lower 10 miles of the river was ordered to be treated on Mr. Walker's plan. In 1845 Mr. Williams showed that the works he had carried out on Mr. Cubitt's plan were in successful action, and that no deposit behind the weirs had taken place, the bottom scour not being diminished; in proof of which he adduced the lifting by the under-current of an old sunken barge from the back of the weir at Holt up to the top of, and over, the weir itself.

The works carried out under Mr. Walker's plan the Commission considered a failure, and again applied to Parliament for power to make the fifth lock, which they proposed to place 4 miles lower down the river at Tewkesbury. In 1851 Mr. Walker reported* against the project to the Admiralty, and stated that his plan for equalizing the river had not been fairly dealt with; but he admitted that the locks and weirs between Worcester and Stourport were a success. The Admiralty, however, rejected his advice, and

* Report to the Admiralty, Sept. 11th, 1851.

the Severn Commissioners were allowed to carry out their project. After some delay the work was carried out, and as described to the Institute of Civil Engineers in 1860, comparing the transverse soundings, taken 16 feet from the head of the weirs, with those taken in 1842, shows an increased depth in the channel of from 3·55 feet, which is also the case in the pools between the weirs; proving that the river has an increased capacity, and therefore that floods must have a freer discharge. Mr. Cubitt did not urge that his project would have this effect, but, when the works were carried out, this good result was found to be the state of the case.

Mr. W. Parkes,* M. Inst. C.E., points out that the pounded river, by facilitating the immediate passage of flood-water by the river channel, increases the proportion of the volume of the flood that is available for scouring purposes. "The disturbance caused by the sudden accession of water at any spot would be transferred down the course of the channel with a velocity depending on the square root of the depth of the water in the channel, and therefore far more rapidly in the pounded than in the unpounded channel. Thus the escape of the flood by the channel was facilitated, and the rise above the banks retarded." He further points out that it is essential "that the weir itself should have a capacity of discharge at least equal to that of the channel above and below; but this was presumed to be provided for by length of weir, when it acted as an overfall, and by width of channel above the top of the weir when it was drowned, below the surface of the flood."

Mr. R. Rawlinson, C.B., refers to the diagrams in one of the *SEVERN* weirs, given in the Rivers Pollution Report, showing that when the flood rose a foot a mile above the weir, it only rose an inch on the weir, and as the river rises foot by foot, inch by inch is added to the weir until it is lost to view, and the flood flows on as if the weir did not exist.

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* Discussion on Weirs. 'Min. Proc. Inst. C.E.,' vol. lx. 1880.

In this case a 10-feet flood is said to be 10 inches of water on the weir, but it is not stated how far the height of 10 feet a mile up the stream is due to the damming back of the water by the weir itself.

Professor Unwin states that he does not consider the value of the oblique weir proved, as the discharging must be measured normally to the direction of flow; and M. de Lagrené states, in the latest French work on navigation, that there are no sound experimental results which give any information on the subject. That floods on the *SEVERN* were reduced by Cubitt's four masonry weirs can be understood when previously there were fourteen natural weirs, or shoals, over which there was only 18 *inches of water.*

Left Bank of the Lower SEVERN.

Professor Judd gives the details of the Lower Oolites at Stroud, which show that they have thinned 70 feet in the 25 miles distance, at Cheltenham; 12 miles still further to the north-east the total thickness is about the same. Calcareous Freestones have greatly increased in thickness at the expense of the Midford Sands.

Formations.	Lithological Character and Thicknesses.					
	Stroud.			Cheltenham.		
	Clays.	Sand-stone.	Lime-stone.	Clays.	Sand-stone.	Lime-stone.
Cornbrash	3	..	12	3	..	12
Forest Marble	36	12	20	21	12	15
Great Oolite (Upper Zone)	10	..	16	43	..	45
Great Oolite (Lower Zone)	..	5	33	..	..	45
Stonefield Slate	..	..	..	3	3	..
Fuller's Earth	49	..	15	9	..	..
Ragstone	..	..	38	..	..	38
Upper Freestone	..	..	16	..	..	34
Oolite Marl	5	..	..	6	..	..
Lower Freestone	..	..	88	..	..	144
Pea Grit	..	..	..	..	38	..
Midford Sands	..	147	..	2	22	10
	103	164	238	87	75	243

Comparing these sections with the Bath Section, it will be seen that there is a steady attenuation in thickness of the clays north-eastward, from 206 feet at Bath to 87 feet at Cheltenham; that the limestones obey the same law, though to a somewhat less extent; and that the sandstones are thickening, especially locally, around Stroud.

A tributary stream rising above Stroud, falling into the *SEVERN* at the bend of the deep "flash" in the course of the stream south of Elmore, has a canal running parallel to it, reaching 63 feet at Eastington, 133 feet at Stroud, and 212 at Minchin Hampton, thence eastward, through the diagonal watershed, at 376 feet, into the *THAMES* Basin, past the *THAMES* Head, to Cricklade, where it is joined by a branch canal from the Bristol *AVON* and *Ock* Canal, near Swindon.

A canal also runs parallel to the *SEVERN*, on its east bank, between Berkeley and Gloucester, which is carried over the Liassic plains, which are crossed at right angles by several small streams rising in the Oolitic escarpment, both below Gloucester and between that plain and Tewkesbury.

Professor Hull describes the two chief sources of springs among the Cotswolds as occurring at the base of the Great Oolite, or Stonefield Slate, at its junction with the Fuller's Earth, and at the junction of the Upper Lias Clay with the overlying sands. To the latter horizon belong the Seven Springs forming the source of the *THAMES*. Smaller springs issue in the district at the base of the Lias Marlstone, and the upper surfaces of Forest Marble Clays.

GLOUCESTER, population, 36,522, is partially supplied by springs in the flanks of Robin's Wood Hill, thrown out by the Lias, which, with the surface drainage of 1500 acres, are collected in a reservoir holding 62,000,000 gallons. The water has nineteen and a half degrees of hardness, which could be reduced to three and a half by Clark's process. Supply, 540,000 gallons; rateable value, 105,380*l.*; Gloucester Waterworks Act, 1855. Rainfall in 1879, at Quedgeley House,

50 feet above the sea, 30·76 inches; at Witcombe Reservoir, 297 feet above the sea, 32·13 inches.

CHELTENHAM.—Population, 43,972; supplied from three springs which are collected along the flanks of the hills in bricked wells, and conveyed to the reservoirs at Hewlett's Hill and Leckhampton, together holding 35,000,000 gallons. Above 300,000 gallons are daily delivered. The water is much softer than most Oolitic springs, the hardness being 15·0, of which only 6·0 is permanent; that of Haydon, near Cheltenham, is no less than 45·7, of which 13·4 is permanent. Cheltenham Waterworks Act. Works lately acquired by the Corporation. Rainfall in 1879, at Hewlett's Reservoir, 232 feet above the sea, 33·50 inches; in 1880, 34·71 inches.

The saline springs of Cheltenham rise, according to Professor Hull, along planes or fissures in the Lower Lias, like the water in artesian borings, and are probably derived from water percolating through salt-bearing Keuper, which outcrops at higher elevations, as first explained by Sir Roderick Murchison.

CHARLTON KINGS.—*Acres*, 3950; population, 3680; supply from *Cheltenham Waterworks*, Hewlett's Hill Reservoir; public and private wells; rateable value, 21,700*l.*

LECKHAMPTON.—*Acres*, 2266; population, 3502; *Cheltenham Waterworks*, Cotswolds Hills, and from sand-bed under district; rateable value, 19,389*l.* 7*s.* 6*d.*

TEWKESBURY.—*Acres*, 3266; population, 5100; *Cheltenham Waterworks;* rateable value, 19,899*l.* Rainfall at Upper Lode, 41 feet above Ordnance Datum, 30·10 in 1880.

BISLEY.—*Acres*, 11,621; population, 5168; wells and springs; rateable value, 13,903*l.*

NEWNHAM, population, 1455; AWRE, population, 1179; and WESTBURY-ON-*SEVERN*, population, 2272, have no public water supply.

STROUD.—*Acres*, 999; population, 7533; reservoirs collect springs, yielding minimum supply of 40,000 gallons, a

maximum of 200,000; average supply of 80,000; rateable value, 20,807*l.*; Public Health Act. Rainfall in 1879, at Brinscombe Port, 200 feet above Ordnance Datum, 31·15 inches; in 1880, 36·47 inches.

UPPER AVON.

This tributary stream is 85 miles long; its drainage area occupies 1050 square miles of the *SEVERN* Basin; this sub-basin is bounded east by the basin of the *THAMES* and Bedfordshire, and north by that of the *TRENT*, the former watershed traversing the Lias, the latter the Keuper Marls. The Oolites occupy 4 square miles, the Lias 686, the Red Marls 320, Keuper Sandstone 8, Permian Sandstone 34, and Coal Measures 2 square miles.

The *AVON* falls into the *SEVERN* at about 38 feet above the sea; at Pershore it has ascended to 56 feet, to 80 feet at Evesham, where it receives the *Isbourne* from the south, to 124 feet at Stratford-on-Avon, where the *STOUR* falls in from the south, whose head waters rise on the opposite side of the watershed; above the source of the *Evenlode* at Warwick it is 188 feet, where it receives the waters of the *Leam*, and is crossed by a canal connecting the *THAMES* and *TRENT* Basins, and crossing the corner of that of *AVON*. At Rugby, the river is a second time crossed by a canal at 316 feet, connecting the basin of the *TRENT* with that of the *NEN*. The canal crosses the watershed into the latter basin at 370 feet near Daventry; just above the source of the *Leam* the branch is carried southwards, and is connected with the Warwick and Oxford Canal, which crosses *Itchin*, a tributary of the *Leam* at 256, and the *THAMES* (*Cherwell*) watershed at 390. The *AVON* is a third time crossed by a canal near its source connecting the basin of the *NEN* and *WELLAND*, and crossing the *AVON* watershed west of Naseby at 420 feet.

It is perhaps worthy of note, that a continuous succession of canals traverse the country from London to Warrington, in nearly a straight line, and that the London and North-

Western Railway runs parallel to them for the whole distance, with an average elevation of 300 feet.

North of the *Avon* and near its source rises the *Sow*, draining the country around Coventry; it is crossed by the Rugby and Nuneaton Canal, which passes into *TRENT* Basin (River *Anker*) at 316 feet; the Rugby and Birmingham Canal crossing into the *TRENT* Basin (River *Blyth*) at 346 feet, and another canal at 464 feet, which terminates at Stratford-on-Avon. Between this town and Evesham, a northern tributary falls into the *Arrow*, with its feeder the *Alne*, crossed by the Stratford Canal, at 240 feet.

Horizontal Section, Sheet 82,* gives details of the thickness of the strata borders of the *THAMES* and *Upper Avon* Basins. At Broom Hill, 720 feet above the sea, the section is 70 feet of Northampton Sands, Ironstone and Siliceous Limestone (with Inferior Oolite fossils in lower part), 70 feet of Upper Lias, 125 feet of Marlstone, rock bed 25 feet, and Sands 100 feet, 400 feet of Lower Lias, and 55 feet of Keuper Marls. A fault with a northerly downthrow (near the county boundary west of Tysoe Hill) brings the Lower Lias to the surface by Oxhill, Compton Verney, and Morton Morrell Church, where the steady southward dip of the Lias causes it to outcrop, and the Red Marls form the surface, by way of Ashorne Hill, to a point near the Birmingham and Oxford Railway, the River *AVON*, and the Warwick and Napton Canal, when the Sandstone and Marls of the Waterstones rise to the surface. The Keuper Marls are represented at 500 feet thickness, and the Waterstones at 100; these form the whole of the Trias of Warwickshire, and rest on the Red and Brown Sandstones with lenticular beds of Red Marls of Permian age. At Milverton Church the surface of the ground is 250 feet above the sea, and the base of the Trias 150 feet below the surface. Gravels of Middle Glacial age around Leamington, Warwick, Lillington, and Milverton supply many shallow wells in this district; the Gravels are

* Published by the Geological Survey of England and Wales.

partially overlaid by Upper Boulder Clay, which is seen in great force in the London and North-Western Railway cutting at Rugby, where a Lower Boulder Clay is also noticeable, but at Leamington the Gravels and the water held by them rest on Keuper Marls.

At Nuneaton, just beyond the watershed, in the *TRENT* Basin, borings in the centre of the town passed through 27 feet of Drift, 81 of soft, light red sandstone, and 15 feet of "Hartshill Stone;" (?) and the water was found beneath in a hard white rock, and rose nearly to the surface. Rainfall in 1880, 34·35 inches.

Coventry.—Population, 42,111; from 4 artesian wells in Permian, sunk through 300 feet of alternations of Marl and Sandstone, one well yielding 800,000 gallons per day. There is a reservoir, tank, 2 pumping engines over 60 horse-power, and one 40 horse-power. The supply is constant; rateable value, 108,080*l.*; Act, 7 & 8 Vict. c. 56. Rainfall in 1879, at Priory Row, 279 feet above Ordnance Datum, 31·65 inches; in 1880, 33·74 inches.

Rugby.—*Acres*, 1617; population, 9890; reservoir holding 14 days' supply, from land drainage and River *Avon*. An artesian well and boring, 1031 feet deep, carried through the Keuper Marls with gypsum and salt, was abandoned after 3000*l.* were spent, owing to the saline character of the water met with; supply, 177,000 gallons; rateable value, 48,000*l.*; Rugby Waterworks Act. Rainfall in 1879 at the School, 383 feet above the sea, 29·11 inches; in 1880, 36·68 inches.

Kenilworth.—Population, 4150. It is stated by the Local Authorities to have no public supply. Rainfall in 1880, 290 feet above Ordnance Datum, 34·35 inches.

Royal Leamington Spa.—*Acres*, 1751; population 22,976; rateable value, 116,489*l.*; supply of 500,000 gallons stored in two reservoirs, filtered through gravel, pumped from River *Leam*, gives constant supply except in droughts. The water is taken above the intake of the Leamington sewage, but below that of Southam. The Rivers Pollution Commission

states total solid impurity to be no less than 68·92, total hardness 27·5, chlorine 2·30; some inhabitants use shallow wells, sample analyzed gave 134·04 of total solid impurity, and 63·9 hardness. The organic compounds show this well to be fed entirely with sewage, though its waters are remarkably bright, and it had a great reputation for purity. A deep artesian well has since been sunk to improve the supply, passing through 15 feet of made ground, blue sand, and sandy red clay, 115 feet of Marls, and 216 feet of bands of Sandstone and Marl, belonging probably to the Keuper Waterstone and Permian beds. Under Public Health Act.

The Leamington Corporation also supply Milverton; *acres*, 1180; population, 2162; rateable value, 19,727*l.* 17*s.* 3*d.* Lillington; *acres*, 1305; population, 938; rateable value, 14,925*l.* Rainfall in 1879, at Upper Parade, 195 feet above Ordnance Datum, 31·23 inches; in 1880, 30·83 inches.

Warwick.—*Acres*, 5512; population, 11,802; rateable value, 45,550*l.*; constant supply of 240,000 gallons from adits in a deep sand-bed underlying a large tract of land on the north-west side of the borough; the Sanitary Acts.

Stratford-upon-Avon.—*Acres*, 5609; populatiom, 8053; private wells and pumps; rateable value, 34,144*l.* Rainfall in 1879, at 123 feet above the sea, 30·28 inches.

Southam.—Population, 1785 in 1871; wells and springs; the Rivers Pollution Commission states the Holywell spring is the best; the total solid impurity was 71·90; total hardness, 42·8; all the rest were dangerously polluted; and comments on the less porous nature of the Lias than the Trias; that a larger proportion of organic impurity escapes oxidation in waters derived from shallow wells; the total solid impurity seldom descends below 50 parts per 100,000, or 35 grains, and mounts up to a maximum of 307 parts in 100,000, or 215 grains per gallon. These waters are not fit for washing from hardness, and certainly dangerous to health from pollution. Rainfall in 1879, at Stockton, 289 feet above the sea, 28·23 inches; in 1880, 31·31 inches.

Evesham.—*Acres*, 2150; population, 5112; from wells; rateable value, 20,493*l*.

Redditch.—Population, 9964; private wells; supply bad; rateable value, 22,400*l*.

Central *SEVERN* Basin.

Left or east bank from Worcester to the infall of the *Vyrnwy*;—this bank almost entirely consists of Triassic and Permian rocks, the exceptions being the Old Red outliers west of Kidderminster, that portion of the South Staffordshire Coalfield that lies within the *SEVERN* Basin, parts of the Coalbrookdale and Shrewsbury Coalfields, and the ancient rock of the Wrekin.

Worcester.—*Acres*, 1285; population, 33,955; constant supply of 1,000,000 gallons pumped from the *SEVERN* and filtered; rateable value, 118,405*l*.; works carried out under Public Health Act, 1848. Rainfall in 1879, 28·62 inches.

River Salwerp.

This stream falls into the *SEVERN* above Worcester. It drains entirely a New Red Marl district, it flows by the village of that name and Droitwich, 105 feet above the sea. *Acres*, 1581; population, 3761; supply from surface wells only; a scheme is proposed for supplying the borough from a reservoir to be made by the Corporation at Tagwell, 1½ mile distant; rateable value, 18,608*l*.

Bromsgrove (District).—*Acres*, 9773; population, 4842; supply from unpolluted stream from Lickey Hills and wells; rateable value, 24,354*l*. Rainfall in 1879, at Tardebigge reservoir, 433 feet above the sea, 33·89; at Upper Bittal reservoir, 518, 36·18.

Bromsgrove (Town).—*Acres*, 871; population, 7959; supply from private wells only; rateable value, 15,234*l*.

River Stour

Is 20 miles in length, falls into the *SEVERN* at 59 feet above the sea. It rises on the South Staffordshire Coalfield,

near Hales Owen; flowing west, it crosses the Gault, and crosses successively the Keuper Sandstone and various Bunter beds, until it receives the water of the *Smestow*, which is canalized, the canal crossing the watershed near Wolverhampton at 352 feet above the sea, the Stour Branch Canal crossing at 454, near Dudley.

Stourport, or Lower Mitton.—*Acres*, 861; population, 3358; supply from private wells only; authority is arranging with Kidderminster Corporation; rateable value, 10,518*l.*

Kidderminster.—*Acres*, 1191; population, 24,270; constant supply of 400,000 to 630,000 gallons, from storage reservoir of 3,000,000 gallons capacity, filled from artesian well; rateable value, 56,610*l.*; Public Health Acts.

Stourbridge.—Population, 9756; constant supply of 400,000 gallons from service reservoir on Bonblecote Hill, filled from artesian well in New Red Sandstone, 50 feet deep, pumped down 30 feet; rateable value, 24,278*l.* 16*s.* 3*d.*; works under Stourbridge Waterworks Company's Act. The Company have purchased two new sites for wells, with tunnel in Sandstone between them.

The *South Staffordshire Waterworks* supply the following Staffordshire towns in the *SEVERN* Basin:—

Wolverhampton (Borough).—*Acres*, 3440; population, 75,738; constant supply of 17½ gallons per head for domestic supply, in all 2,000,000 gallons; from a storage reservoir holding 10,000,000 gallons, and covered service reservoir containing 1,500,000 gallons of water pumped from the River *Worf*, a tributary of the *SEVERN*, in the county of Salop, and strained through a wire gauze; and from an artesian well 918 feet deep, upper half of 24 inches diameter, and lower of 15½, and another 300 feet deep and 7 inches diameter, and two ordinary wells; rateable value, 220,000*l.*; works carried out under Wolverhampton Improvement Act, 1869; the works were originally constructed by a company; additional pumping plant at the wells and storage room are required. Rainfall at Thorganby, at 459 feet above Ordnance Datum, in 1879, was 30·44 inches; in 1880, 33·54 inches.

Brownhills, population, 10,967; supply partly from private wells; rateable value, 38,624*l.* 9*s.* Darlaston, *acres*, 777; population, 13,574; supply constant, but the water requires filtration; rateable value, 33,723*l.* 5*s.* Dudley, *acres*, 3536; population, 46,233; supply, 20 gallons per head, exclusive of trade; rateable value, 119,499*l.* 16*s.* 8*d.* Rowley Regis, *acres*, 3840; population, 27,385; supply partly from springs; rateable value, 90,000*l.* Tipton, *acres*, 2697; population, 30,013; supply constant; rateable value, 86,676*l.* Upper Sedgley, population, 14,874; supply partly from wells; rateable value, 25,853*l.* Smethwick, *acres*, 1882; population, 25,076; supply intermittent of 24 gallons per head, supplemented by private wells; rateable value, 86,000*l.* Brierley Hill (Worcester), *acres*, 1027; population, 11,546; intermittent supply, supplemented by private wells; rateable value, 33,276*l.* 1*s.* 1*d.*

The district of supply of the South Staffordshire Waterworks within the *SEVERN* Basin is between 50 and 60 square miles, and is chiefly drained by the River *Stour*.

Bridgenorth (Salop).—*Acres*, 2987; population, 5890; the large parish of St. Leonard is on the west bank of the river, the part of the town east of the river is the parish of St. Mary Magdalene; constant supply from spring a mile from the town, stored in a reservoir.

River Worf.

The *Worf* is 13 miles long; it rises north of Shiffnal, on the Permian, crosses the Lower Mottled Sandstone, Pebble Beds, and Upper Mottled Sandstone, and follows the strike of the latter for several miles, to Worfield, whence it turns westward, and flows up the dip of the Trias, falling into the *SEVERN* at a point where it traverses the Lower Mottled Sandstone.

North of the infall of the *Worf*, the *SEVERN* traverses the Permian and enters the Coalbrookdale Coalfield, and, turning westwards at Ironbridge, ceases to follow the strike of the Triassic rocks.

River Tern.

This river is 23 miles long, rises in the extreme north-eastern corner of the *SEVERN* basin, which terminates against the boundaries of the *WEAVER* and the *TRENT*. It flows over Bunter Beds, by Market Drayton (where it is crossed by the Birmingham and Liverpool Junction Canal), Tern Hill, Child's Ercal, and Great Bolus (where it receives the *Mease* on the left bank), waters Upton, north of Wellington, west of which it receives the *Roden* on its right bank, falling into the *SEVERN*, north of Wroxeter, at Child's Ercal.

The *Mease* rises near Newport, and is 10 miles in length, flowing over Triassic Sandstones.

NEWPORT (Salop) is 242 feet above the sea.—*Acres*, 561; population, 3044; supply not known to the clerk of the Authority, probably none of a public character; rateable value, 8987*l*. Rainfall in 1869 was 31·29 inches.

WELLINGTON (Salop). — Population, 6202; intermittent supply from small rivulet, occasionally increased by heavy rainfall; rateable value, 18,500*l*.; Wellington (Salop) Waterworks Act, 1860. Rainfall in 1879 was 28·36 inches; in 1880, 30·93 inches.

River Roden.

This stream is 20 miles long. A feeder rises south of Whitchurch, by Prees, and falls into the main stream at Wem. The chief feeder rises at Welsh Hampton, near Ellesmere, thence to Wem, Morton Corbet, and High Ercal.

ELLESMERE.—Population, 1875; supply from contaminated wells in the Sands of the Middle Glacial Drift; rateable value, 7506*l*.; gravitation scheme suggested.

The Triassic belt traversed by the *Tern*, at its infall into the *SEVERN*, is let in by trough faults, running about north-east. The latter river then flows for a short distance over Coal Measures, overlaid by Permian, which rocks are again thrown down by a third parallel fault, at Shrewsbury, where the river has risen to 192 feet above the sea.

SHREWSBURY.—*Acres*, 3470; population, 26,478; intermittent supply of 640,000 gallons, of which 600,000 is pumped from the *SEVERN*, the rest from springs in the New Red Sandstone, stored in a reservoir; rateable value, 104,500*l.*; works under Shrewsbury Waterworks Act, 1856, 19 & 20 Vict. Water would be improved by filtering. Rainfall at 238 feet above the sea, in 1879, 25·22 inches; in 1880, 29·08 inches.

North of Shrewsbury the *SEVERN* curves very considerably, and between Fitz and Montford receives the waters of the *Perry*, 10 miles in length. The stream rises near the *DEE* watershed, between Oswestry and Ellesmere, and drains a Triassic Sandstone area.

The *Vyrnwy* falls into the *SEVERN* at Melverley.

CHAPTER XXII.

UPPER SEVERN BASIN.

The Upper *SEVERN* and its tributaries the *Tanat* and the *Vyrnwy* drain an area of 1320 squares miles, of which probably 1300 square miles consist of impermeable Silurian and altered rocks, the rainfall off which, ranging from 56 to 114 inches, flows with great rapidity, though after long dry summer weather the evaporation of the rain falling on the bare heated rocks is considerable. The valleys are broad and flat bottomed, and adapted to the requirements of reservoir-making, being in places sufficiently contracted to allow a bank or dam to be thrown across them. Their adaptability for this purpose was first noticed by Mr. Bateman, who proposed to collect the water given by 36 inches of rainfall, flowing off 204 square miles, for the supply of London, with a reserve of 109 miles in the *SEVERN* and 60 in the *WYE*, which he estimated would yield 220,000,000 gallons per day, after allowing one-fourth of the supply for compensation.

Geology of the older Rocks of the West SEVERN and WYE Basins.—The Upper Old Red Sandstone rocks at Micheldean, in Gloucestershire, are beds of passage; they consist of yellow sandstones, with *Lepidodendron*, micaceous white sandstones with plant fragments, resting on Old Red Marls with sandy and marly "cornstones"; these consist of impure concretionary limestone, occurring in irregular masses.

The uppermost Silurian strata consist of thin-bedded micaceous Sandstones, known as the "Tilestones"; they are used for roofing purposes, but are never cleaved like the slate of Cambrian and Lower Silurian age. On the same horizon is the "Bone-bed" of Ludlow and Malvern, and

the *Lingula* and "*Trochus helicites*" bed, near Builth and Kington, and found occurring in the base of the Old Red outliers near Knighton and Clun. Below these occur the Upper Ludlow Calcareous Sandstones, with shells, and occasional pebbles of quartz.

Below these beds in Shropshire is the Aymestry Limestone, which is compact, of a grey colour, and fossiliferous; the shell *Pentamerus Knightii* being characteristic. It is very inconstant, and is not present in South Wales.

The Lower Ludlow consists of brown and bluish-grey sandy shales and sandstones, well developed round Ludlow, and extending to the banks of the *USK*.

Below it is the *Wenlock Limestone*, taking its name from Wenlock Edge, where it is well seen. Good exposures occur also at May Hill and Woolhope, in the Abberley and Malvern ranges. It is called the Dudley Limestone at Dudley and Walsall. These beds in the May Hill district are 230 feet thick, and are the chief source of agricultural lime, the best being obtained from the base, where the beds are solid and pure. It is full of a chain-coral. The Wenlock Shale varies from calcareous and slaty flagstones to soft shales used for brickmaking in Shropshire and Gloucestershire.

The *Woolhope Limestone* is interstratified with the base of the Wenlock Shales in the Woolhope district, Herefordshire, near May Hill in Gloucestershire, and near Malvern. It is highly crystalline, and used for lime-burning at Yat Hill, near Old Radnor, and near Presteigne.

Denbighshire Grits and Flagstones form the base of the Wenlock series from the mouth of the *CONWAY* in North Wales to the upper waters of the *Ithon*, north of Builth, when it disappears at Bedd Ugre, near Pen-y-bont. This division consists of micaceous Sandstones, quartzose Grits, and Conglomerates with white quartz pebbles of great thickness, with occasional Wenlock fossils. From Newbridge, southwards, the Wenlock Shale either rests directly on the Tarannon Beds or overlaps them, and passes on to the Lower Silurians. This is also the case wherever the base of the

Wenlock Shale is seen on the eastern margin of the Upper Silurian tract, from the River *Tanat* to the Stiper Stones, or rests on the Lower Silurian, and eastward to the Longmynd on the Cambrian, and at Caer Caradoc again on the Lower Silurian; northward, to the Wrekin, the Upper Llandovery Grit intervening, the latter full of *Pentamerus oblongus*, resting on the denuded, upturned, and nearly vertical edges of the Cambrian Grits and Llandilo Slates.

Upper Llandovery rocks, sometimes called the *Pentamerus* Beds, from the prevalence of *P. oblongus*, by Professor Sedgwick the May Hill Sandstone, from May Hill, where it is well developed. It varies from a brecciated conglomerate, with pebbles of granite, to a fossiliferous calcareous Sandstone.

Lower Silurian rocks:*—*Lower Llandovery Grits*, Slates and Conglomerates, with quartz pebbles, indicating oscillations of level. Equivalent in age to the Bala Beds of North Wales are the Caradoc Sandstones of Shropshire; they are true Sandstones, unaltered fossiliferous freestones. Interbedded volcanic rocks are absent. Thin bands of limestone occur interbedded at Church Stretton.

River Vyrnwy.

Has a length of 29 miles, rising on the Caradocs of the central Welsh watershed, immediately south of Bala Lake, rising to 2050 feet, and flanked to the west by the still greater elevations of Aran Mowddy and Aran Benlyn. Flowing south-east, it crosses at right angles the synclinal of Upper Silurian rocks, consisting of the Denbighshire Grits, flanked on either side by Tarannon Shale. In the broad and deep valley at Llanwddyn, consisting of these formations, Mr. Bateman proposed to place one of his reservoirs for the supply of London. The site has been also chosen for the scheme for the supply of Liverpool and district; and since

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* For details of the Lower Silurian rocks of this area see Professor Ramsay, 'Geology of North Wales,' vol. iii. of the 'Memoirs of the Geological Survey,' also Catalogue of the Rock Collection at the Museum of Practical Geology.

adopted by the Corporation of that city, and powers granted for its execution by Parliament. In the scheme for London, the water to be impounded in this reservoir was turned into the stream, and intercepted by a conduit, at Pont-y-Brithdir, which was to have followed the valley for rather more than 2 miles, and terminated in a tunnel conveying the water into the *Banw* valley, at a point near the base of the embankment of the lowest of these projected reservoirs for that valley, from which started the line of aqueduct from Ryd-y-gro, which was to have conveyed 130,000,000 gallons a day from the united valleys.

In the Liverpool scheme, the waters impounded in the Llanwddyn reservoir * will be conveyed by a tunnel, 2¼ miles in length, into the *Hirnant* valley, a tributary of the *Tanat*, contouring the latter valley; the aqueduct crosses the watershed, and enters the basin of the *DEE*, near Ellesmere. Mr. Symons, F.R.S., states: "At Llanwddyn, 750 feet above the sea, the rainfall for the five years 1867–1872 (1869 not taken) was 73·44 inches, computed true mean 67·52, minimum 56·80 in 1870, maximum 84·40 in 1872. At the head of the *Vyrnwy*, 1740 feet above the sea, for the same years, was 82·28, computed true mean 76·68 inches, maximum 113·80 in 1872, minimum 63·60 in 1870." These observations were probably taken at Mr. Bateman's No. 5 and 6 stations respectively.

Rainfall in 1880 in Llanwddyn district observed by Mr. Symons:—

	Feet above Sea.	Inches.
Daffrn-newydd	750 ..	48·74
„ „	800 ..	46·34
Hoel-y-ffridd	800 ..	62·52
Cefn-glas	1650 ..	74·20

The *Vyrnwy* from Pont-y-Brithdir continues a south-easterly direction until it receives the waters of the sub-

* The reservoir is calculated to hold 12,000 million gallons, and to supply a daily average (including compensation water) of 52 million gallons. The contributing area is 17,583 acres, and the flow varies from 2 to 700 million gallons daily. The first contribution of water is to be delivered in Liverpool in 1885.

tributary the *Banw*, south of Meifod, where it assumes the direction of the latter, and flows north-east parallel to the *SEVERN*, until it receives the waters of the sub-tributary the *Tanat*, when it again turns south-east, and flows over a flat alluvial tract, and falls into the *SEVERN*.

The sub-tributaries of the *Vyrnwy* drain an extensive area, commencing on the north or left bank, and following it from its infall into the *SEVERN*. A stream comes in at Llandysilio, rising near Hengoed on the *DEE* watershed, and flowing past—Oswestry.—*Acres*, 1754; population, 7851; constant supply of 250,000 gallons, from three storage reservoirs holding 9,000,000 gallons, from gathering ground at Penygwelly conveyed 5 miles by gravitation; rateable value, 27,855*l.*; the works carried out under the Oswestry Water and Sewerage Act, 1865, and Local Government Acts.

Afon Tanat

Has a length of 26 miles; rises in the *DEE* watershed east of Bala Lake, forming the Berwyn Hills, 2718 feet in height, on Tarannon Shales, and flows eastward over Lower Llandovery, Bala, and Llandilo beds, with contemporary volcanic rocks, all of which are practically impermeable. The whole course of the stream is over Lower Silurians.

The *Upper Tanat*, and its tributary the *Swrch*, which falls in near Llanrhaiadr, and other feeders, in all occupying 64¼ square miles, were part of Mr. Bateman's supplementary scheme for London, and a reservoir was proposed on it at Llangedwyn by Mr. Hugh Williams as part of his Liverpool scheme, from which a conduit would have conveyed the water by Oswestry over the *DEE* watershed without tunnelling.

About 1¼ mile above the infall of the *Tanat*, a tributary comes in draining the district around and above Llanfyllin, consisting of Bala Beds. No other important feeder comes in on the north bank, and the south bank from the source of the river only receives small feeders, until the *Banw* joins the *Vyrnwy* near Meifod, which is 9 miles in length, rising in the central Welsh watershed, overlooking the basin of the

DOVEY, which here attains an elevation of 1981 feet, the lower passes being about 750 feet. Mr. Bateman proposed to impound its upper waters at Garthbibio, and those of a southern affluent above Llangadfan; the water stored in these two reservoirs was to have flowed into a third, covering the valley between Can Office and Rhyd-y-Gro. This drainage area, with that of Llanwyddyn, occupies 66,380 acres, or 103¾ square miles. The conduit, commencing at Rhyd-y-Gro, was to have crossed the river at Llanfair, and was contoured over the minor watershed to the *SEVERN*, crossing the river and the Montgomeryshire canal near Berriew south of Welshpool, to Marton Mere, when it joined the *SEVERN* aqueduct, conveying an equal quantity; the united conduit being capable of carrying 260,000,000 gallons a day. The *Banw* from its source to Can Office flows over Denbighshire Grits, then over Ludlow rocks, to Rhyd-y-Gro, then over Bala beds, to a point west of Llanfair, where it again passes on to the Ludlow rocks, following their strike, and falling into the *Vyrnwy*. Rainfall at Lluest Fawr, Garthbibio, in 1880, 990 feet above the sea, 54·30 inches.

Following the course of the Upper *SEVERN*, from the infall of the *Vyrnwy*, it flows through a strike valley in the Silurians, by Welshpool and Montgomery. Lower Silurian rocks occupying the valley, and Upper Silurians the hills above; between Montgomery and Newtown it commences to cut across the strike, and passes on to older and older beds of Silurian age.

River Tarannon.

West of Newtown the river passes out of the Lower Silurian rocks, and receives on the north bank at Caersws the *Carno* stream, which Mr. Bateman proposed to tap, and convey by conduit to his projected Trefeglwys reservoir, on the River *Tarannon* and River *Ceryst*, which unite and fall into the *SEVERN* about a mile above the infall of the *Afon Carno*. The head waters of the *Tarannon* rise at 1475 feet above the sea, on the opposite side of the ridge to those of

the *DOVEY*, in a synclinal of Denbighshire Grits, west of Carrig Hir. Another tributary comes in on the north bank, the *Clywedog*, above the Llanidloes, on the upper waters of which Mr. Bateman proposed to place a small reservoir. The watershed attains an elevation of 1750 feet.

The drainage area of the *SEVERN* above Llanidloes is 12,381 acres, or 19¼ square miles; its source is a little to the north-east of Plynlimmon Fawr, which rises to a height of 2643 feet. The southern margin of this basin is bounded by the watershed of the *WYE*, and then by the *SEVERN* tributary streams the *Afon Tylwch* and *Dulas Brook*, on which Mr. Bateman proposed to place reservoirs from which he carried a conduit crossing the *SEVERN* and *Clywedog* to the Trefeglwys reservoir, which would have there impounded the drainage of 64,192 acres, or 100¼ square miles, which he considered would yield 130,000,000 gallons a day. The conduit was to have commenced at the embankment of the reservoir, and followed the lines of the *SEVERN* valley by Newtown, contoured so as to pass Montgomery and Cherbury, and join the *Vyrnwy* aqueduct at Marton Mere. Thence it was to have passed, by Wenlock, Stourbridge, Bromsgrove, Warwick, Banbury, and Aylesbury, to the service reservoir at Edgware, near London.

Welshpool (Montgomeryshire).—*Acres*, 19,600; population, 7090; constant supply of about 300,000 gallons, from a pool 1½ mile distant from the town, leased from the Earl of Powis for 200 years at a nominal rent. There are two filter-beds, but additional storage room is required; rateable value, 11,300*l.* (town taking water supply of borough 39,000*l.*); Public Health Acts.

The southern watershed of the Upper *SEVERN*, from its source to the infall of the *Vyrnwy*, runs parallel to the river, and but 4 to 5 miles from it, bounding to the west the basin of the *WYE*, and to the east tributaries to the *SEVERN;* the area consists entirely of Silurian impermeable rocks, which disappear to the east under the Shrewsbury Coalfield, which rests on the denuded edges of the Lower and Upper Silurian,

without the intervention of the Carboniferous Limestone or Old Red Sandstone. The base of the Coal Measures, from the infall of the *Vyrnwy* to the village of Westbury, nearly defines the boundary of the Upper *SEVERN* basin.

Llanidloes (Montgomeryshire).—Population, about 3421; no public supply, only about 25 pumps; rateable value, 4988*l.* Rainfall, at 950 feet above the sea, in 1879, 51·50 inches; in 1880, 60·80 inches.

Newtown and Llanllwchaiarn.—*Acres*, 7162; population, 7170; constant supply of 70,000 gallons, 200,000 available from reservoir in the *Cwm-yr-Hendre* brook 4 miles distant, draining a catchment basin of 71,200 acres in the Kerry Hills. Rainfall in 1879, at Caersws, 35·77 inches; in 1880, 32·50 inches.

Montgomery.—*Acres* in registration sub-district, 33,386, with a population of 5721.

CHAPTER XXIII.

RIGHT OR WEST BANK OF THE MID AND LOWER SEVERN BASIN.

From the *Vyrnwy* infall to Shrewsbury the country consists of Coal Measures, overlaid by the Lower Permian, and Red and Purple Marls and Sandstones, surmounted at Alberbury and Cardeston by a stratified breccia, described by the late Sir Roderick Murchison* as consisting of angular fragments of white quartz and carboniferous limestone cemented by calcareo-ferruginous paste. The deposit is regarded by Professor Hull as an old shingle beach.

The coal seams of this district are thin and unimportant, the Lower Coal Measures are absent, and the whole series represent a shallow and shelving shore. Near the top is a band of limestone about a foot in thickness, known as the "Spirorbis Limestone," from the annelide, *S. carbonarius*, which is found over not less than 10,000 square miles, from Warwickshire to Lancashire, though seldom attaining a greater thickness than in the Shrewsbury district; associated with *Spirorbis* is an Anthracosia (freshwater mussel), and the small shell of a crustacean—*Cythere*.

The tributary river *Rea* falls into the *SEVERN*, rising near Trelystan, and, flowing by Worthin over Ludlow rocks, enters the Coal Measures north of Pontesbury, and flows over them, by Hanwood and Mocle Brace, to its outfall.

Another tributary drains part of the Cambrian area lying between the Stiper Stones and the Longmynd, and the Coal Measures north of Caer Caradoc; thence to Stapleton; enters

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* 'Silurian System,' p. 63.

the Permian at Condover, Barrington, and the Bunter Sandstones, near its outfall at Cressage.

The watershed again runs parallel and close to the *SEVERN* from Much Wenlock to Abberley, the country to the west around the Clee Hills and Ludlow being drained by the tributary river *Teme*.

Wenlock.—*Acres*, 8821; population, 2531 in 1871; supply is only from wells and springs, and the Board have no suggestion to offer; rateable value, 16,043*l*. 19*s*. 9*d*. Rainfall, at Larden Hall, at 658 feet above Ordnance Datum, 34·09 inches; in 1880, 36·92 inches.

Broseley.—*Acres*, 1913; population, 4458; supply only from springs, pumps and wells, but a scheme is in progress; rateable value, 10,305*l*.

The Upper Silurian rocks of Wenlock dip south-east under the Old Red Sandstone, overlaid by the southern portion of the Coalbrookdale Coalfield, which to the north overlaps the Silurians. The investigations of Professor Prestwich have shown that, of the 13 coal seams present in the northern part of the field, only the top seams are present to the south, the whole of the base of the middle and the whole of the Lower Coal Measures wedging out southwards, until, at the southern margin, the *Spirorbis* Limestone is within 170 feet of the Silurians on which they rest. This bed is associated with the Upper Coal Measures, consisting of mottled clays, greenish grits, and a calcareous breccia, resembling volcanic scoria, often resting on an eroded surface, or bank of Lower Coal Measures. A narrow strip of these Measures connects this Coalfield with that of the Forest of Wyre, which rests on Old Red Sandstone, consisting of concretionary earthy limestones, associated with Red Marls and Sandstones, which Professor Hull believes to be referable to the age of the Estuarine Devonian.* The Mountain Limestone, Millstone Grit, and Lower Coal Measures are alike absent here. At Arley Colliery, near Bewdley,

* 'Quart. Jour. Geol. Soc.,' May, 1880, p. 268.

under 454 yards of measures were penetrated, and a mass of basalt reached.

Over the Coalfield is the series of Lower Permian age, consisting of Red Sandstone and Marls with Calcareous Conglomerates, which are so fully developed at Enville, to which Professor Ramsay, LL.D., has ascribed a glacial origin. These Coalfields Professor Hull, LL.D., considers to be part of a sheet once continuous with the South Wales Coalfield and Gloucestershire, fragments of which are left on the Clee Hills, where a small area of workable coal occurs at 1780 feet above the sea, resting on the Old Red Sandstone, with some traces of Carboniferous Limestone and Millstone Grit, at Tetterstone Hill.

This Coalfield lies in a trough or basin of Old Red Sandstone, for this formation appears on the surface on the eastern margin, both north of Kidderminster and between Abberley and Stourport; everywhere on this side of the Coalfield it is faulted in a north-east direction against the Bunter Sandstones.

The central portion of the Forest of Wyre is drained by a small tributary forming the boundary between the counties of Shropshire and Worcestershire, falling into the *SEVERN* at Bewdley, on the edge of the Triassic plain through which the river flows southwards.

Bewdley.—*Acres*, 2840; population, 3088; supply from private wells only, no public scheme is suggested; rateable value, 8000*l*.

The southern inlier of Old Red is drained by a small tributary falling into the *SEVERN* below Stourport. Crossing the boundary fault, this stream flows over Bunter Sandstones, which, with the exception of the small tract lying at the southern termination of the Malvern Hills, is the last exposure of these rocks. A line drawn from the Malvern Hills to Charnwood Forest probably marks the southern termination of the Bunter or Lower Trias. From this tributary to the *Teme* infall, the west bank of the *SEVERN* consists entirely of Keuper Sandstones and Marls.

River Teme.

This river falls into the *SEVERN* immediately below Worcester, at a height of 30 feet above the mean sea-level. Tracing its course from its outfall, it has a general west-north-west direction; the first 7 miles is over the Keuper Marls, thence passing through the break of continuity, in the strike of the ancient rocks of Malvern and Bewdley, it enters the Old Red Sandstone area, and turns abruptly northwards, then westward by Tenbury, at 172 feet, and Ludlow, at 272 feet, a few miles west of which town it reaches the Upper Silurian escarpment, and receives several tributaries; from Ludlow to its source past Knighton, at 570 feet, and Bettws-y-crwyn, at 868 feet, it drains the Upper Silurian rocks, here and there capped by outliers of Old Red Sandstone. Between Tenbury and Ludlow the river is crossed, at 246 feet, by a canal, which falls into the *SEVERN* opposite the outfall of the *STOUR*, and the other end of which falls at Kington into the *Arrow*, an affluent of the *Lug*, tributary of the *WYE*, the watershed of which is crossed at about 250 feet.

Ludlow.—*Acres*, 280; population, 5035; intermittent supply of drinking water from neighbouring springs; the town has another public supply for domestic purposes from the river *Teme;* the Authority is considering an improved supply; rateable value, 13,715*l.* 17*s.* 6*d.*

Knighton (Radnorshire).—Population, in 1881, 1720; intermittent supply from two reservoirs, storing springs; rateable value, 505*5l.*; Public Health Act, 1848.

Tenbury.—Rainfall in 1879, at Orleton, 200 feet above the sea, 34·46.

No tributaries of importance fall into the *Teme* on its right bank. On the left bank the first is the *Rea*, 15 miles long. On it are Cleobury, 172 feet, and Aston Botterell. It chiefly drains the Old Red Sandstone lying east of the Clee Hills. This tract of Old Red, lying between Ludlow and Cleobury Mortimer to the south, Wenlock on the north, and the Ironbridge Coalfield to the east, is the base of the

true Old Red Sandstone of South Wales. It will be noticed that its basement bed, in ranging from near Haverford West in the extreme south-west of South Wales to Wenlock, in advancing to the north-east rests on higher horizons of the Silurian rocks, traversing first the Llandilo Beds, then the Bala, then the Lower Llandovery, passing on to the Upper Silurian west of Llandilo, traversing in succession the Llandovery, the Wenlock, and the Ludlow rocks; the overlap thus extends over nearly the whole of the Silurian system, ranging as it does over the Llandilo beds to the Ludlow rocks.

Taking the mean east-north-east direction of the base-line of the Old Red from Haverford West to the River *Teme* between Tenbury and Ludlow, and continuing this across the Midland Counties of England, it will pass across the Trias of Kidderminster, Birmingham, and Leicester, the Lias and Oolite of Melton Mowbray and Bourn, to the sea at Boston, on the Wash. It will be noticed that the ancient rocks of Charnwood Forest come to the surface immediately north of the supposed boundary, and that no trace of the Old Red Sandstone is there seen. South of the South Wales Coalfield synclinal, a sharp anticlinal brings the rocks beneath the Mountain Limestone to the surface, and here they assume the ordinary Old Red character found north of the Coalfield.

The old dividing ridge, that separated the Old Red area of South Wales from the Devonian of North Devon, must have ranged along the line of the existing Bristol Channel. If this southern boundary of the true Old Red was at all parallel to the northern one, it would range by Bristol, Oxford, Hitchin, and Bury St. Edmund's. It is worthy of note that, about 15 miles south of Hitchin, the *New River Company* have bored through the Secondary rocks, and found all the older Secondary and newer Palæozoics absent, and the Gault to rest upon the Ludlow rocks. While, 30 miles south of Hitchin, the boring at Messrs. Meux's, at Tottenham Court Road, proves the Devonian rocks under London. The

shortest distance between the Old Red Sandstone north of the Bristol Channel and the Devonian south of it is about 20 miles; in part of it probably both formations are absent, and Silurian rocks occupy the sea-bed. That this is the case is supported to a certain extent by the appearance of Silurian on the surface on the east bank of the mouth of the *SEVERN*, near Wootton-under-Edge; Silurians re-appear on the opposite side of the river, and bound the Old Red at Micheldean.

The Malvern and Bewdley Hills are a continuation of the strike of this range, and form the eastern margin of the Old Red Sandstone tract, but whether they are present on the eastern slope of these hills beneath the Trias of the Midlands there is little evidence to show. Continuing the strike of the Wenlock escarpment north-eastwards, and continuing the strike of the Malvern and Abberley Hills northward until they meet at Shifnal, a small triangular area beneath the Coalbrookdale Coalfield will be reached, under which it is certain the Old Red is present. The Silurian rocks may form a rim or margin to the east, as they do to the west; but, on the other hand, these ancient rocks may rise above the surface of the Old Red, which may sweep round their eastern flank. That it did so to a certain extent is proved by the Old Red Sandstone outlier, west of Stourport, which is faulted against Trias to the east, and overlaid directly by Coal Measures to the west.

The *Corve*, sub-tributary, is 5 miles in length; on it are Staunton Lacey, Tugford, and Skipton, the average rainfall is 25·9. Rising south of Wenlock, it flows in the direction of the strike of the Old Red close to its base. The eastern slope of the valley is all on that formation; the western slope drains the Ludlow rocks with Aymestry Limestone, on the east slope of Wenlock Edge. The *Corve* falls into the *Teme* at about 280 feet above the mean sea-level.

The *Onny* falls into the *Teme* at 297 feet. It is 12 miles in length; it rises in the Lower Silurian hills around Shelve, and then passes on to the Wenlock; its northern affluent

drains the Stiper Stones, the Cambrian of the Long Mynd, the Lower Silurian of Caer Caradoc, and the valley lying between Church Stretton and Wenlock Edge.

The sub-tributary, the *Culn* or *Clun*, is 14 miles in length; it falls into the *Teme* at about 400 feet above the sea, rises in hills east of Newtown, forming the county boundary between Salop and Montgomery, and consisting of Old Red outliers resting on Wenlock. It flows eastward, past Clun, until it reaches a great fault, through a narrow strip of Cambrian, after which it turns abruptly southward, and follows the strike of the Wenlock Limestone until it falls into the *Teme*.

The west bank of the *SEVERN*, between the infall of the *Teme* and the watershed of the *Leadon*, consists of Keuper Marls, flanked to the west by the fine escarpment of the Malvern Hills, composed of impermeable Upper Silurian rocks and Felstone.

Great Malvern.—*Acres*, 1328; population, 5847; supply, from 30,000 to 200,000 gallons, average 50,000; from storage reservoir impounding springs in the hills; rateable value, 47,164*l.*; Malvern Improvement Acts. Rainfall at Hornyhold Terrace, Great Malvern, 550 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
33·88	29·54	34·22	34·22	34·57

Malvern Link.—*Acres*, 225; population, 1800; no public supply; rateable value, 787*6l.*

Upton-on-Severn.—[No information.]

Lower *SEVERN*—*Right Bank.*

From the infall of the Warwickshire *Avon* at Tewkesbury to the sea, the *SEVERN* runs nearly in the line of the boundary of the Keuper Marls and the overlying Lias, the former forming the right bank and the latter the left. The larger part of the right or west bank is drained by the tributary *R. Leadon*, about 24 miles long; rising on the Old Red, west of

the Malvern Hills, and flowing past Ledbury, it enters the Keuper Marls between Dymock and Bed Marley, and drains an entirely impermeable basin. Within the watershed is Newent.

East of Micheldean occurs an Upper Silurian inlier, bounded to the west by the overlying Old Red, and to the east of the Keuper Marls, which overlap in succession the Old Red, Ludlow rocks, and Denbighshire Grits.

The western area is occupied by the larger portion of the Forest of Dean, which is underlaid by the Millstone Grit and Mountain Limestone, which outcrop around the Coalfield, rising above it, and overlooking the valley of the *SEVERN*, to the Cotswolds beyond. The Coal Measures, with fifteen coal seams, are stated by Sir Henry De la Beche* to be 2765 feet thick, the Millstone Grit 455 feet, the Carboniferous Limestone 480 feet, the Lower Limestone Shale 165 feet, and the Old Red Sandstone 8000 feet or more. The Carboniferous strata have decreased in thickness by two-thirds compared with the Bristol district. The Measures are horizontal in the centre of the basin, and rise towards the margin, especially near the eastern edge. The seams are being worked back from the margin towards the centre, which will be found heavily watered.

At Westbury the Rhætics occur between the Keuper Marls and the Lias, the Marls continuing by Newnham to Blakeney, south of which the Old Red Sandstone forms the coast-line, by Sydney, to Woolaston, where it is overlaid by Red Marls, which gradually overlap the Carboniferous Limestone at the mouth of the *WYE* at Chepstow.

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* 'Mem. Geol. Survey,' vol. i. p. 203.

CHAPTER XXIV.

THE WYE AND USK BASINS.

RIVER WYE (CXI.).

This river has a length of 135 miles; area, 1609 square miles, of which Silurian rocks occupy 598 square miles, Old Red 966, Carboniferous Limestone 14, Coal Measures 25, and Trias 6. The source of the *WYE*, like that of the *SEVERN*, is on the eastern crest of Plynlimmon, 2481 feet in height, one of the prominences in the long *central watershed* traversing Wales in a curve running parallel to its western coast-line, extending from St. David's Head, by Plinlimmon and Snowdon, to the Menai Straits at Carnarvon, re-appearing in Anglesea, and separating the waters that flow respectively east and west. In Wales it separates all the streams which flow with steep and rapid fall into Cardigan and Carnarvon Bays, from those flowing with low gradients eastwards into the basins of the *DEE* and the *SEVERN*, or in the sea now covering lands formerly drained by these rivers. The principality may therefore be naturally divided into South and Mid Wales, draining into the *SEVERN*, its tributaries, and rivers formerly tributary to it; West Wales, drained by small streams, draining directly into the sea, with an average distance from the watershed to the sea-coast of only 20 miles; North Wales, draining into the *DEE*, or rivers formerly tributary to the *DEE*.

From Chepstow to Tintern Abbey the *WYE* flows through the fine cliffs of Carboniferous Limestone, which give so picturesque an aspect to the scenery of this district.

Chepstow (Monmouthshire).—*Acres*, 1000; population, 3585; intermittent supply of 100,000 gallons from reservoir

in parish of Newchurch East; rateable value, 12,000*l.*; works under 6 Vict., sess. 1843; Chepstow Water Company's Act, 6 Vict., 1843; Local Authority wish to purchase the undertaking.

COLEFORD.—*Acres*, 2574; population, 2709; constant supply from a spring above the town; a reservoir is in course of construction; rateable value, 2595*l.*; Public Health Act, 1875.

At Monmouth the south-easterly direction of the tributary of the *WYE*, the *Monmow*, is continued by the main stream, which trending south-west, comes in at right angles, intercepting the Carboniferous Limestone escarpment several times in its remarkable S-like curves. Following the *WYE* Valley upstream, at Walford it again changes its general direction, and trends northward to Ross, and then turns again north-westward, running parallel to the *Monmow*.

MONMOUTH.—*Acres*, 5707; population, 6112; supply of 40 gallons a head from River *WYE;* under the Monmouth Gas and Water Provisional Order, 36 & 37 Vict., 1873, also by private pumps and two public pumps; rateable value, 19,165*l.* Rainfall in 1879, at Dingestow Court, at about 250 feet above the sea, 31·82 inches; in 1880, 34·90 inches.

Ross (Herefordshire).—*Acres*, 107; population, 3724; reservoir collects water from a spring, and the River *WYE*, which is filtered; the supply is intermittent; rateable value, 11,692*l.* 13*s.* 6*d.* Rainfall in 1879, at Rocklands, 108 feet above Ordnance Datum, 32·20; in 1880, 37·00; at The Craig, 213 feet above Ordnance Datum, 32·13 inches in 1879; 35·49 inches in 1880.

River Lug.

At How Caple, the river "flashes," or curves in a loop 4 miles in length, and but little more than a mile in width. At Mordiford it receives the waters of the tributary the *Lug*, 40 miles in length, and draining a large area. Immediately east of this infall is a large outlier of Upper Silurian rocks, around Woolhope, the oldest strata being the Denbighshire

Grits, in the centre of the tract, which dip away in all directions under the overlying Ludlow Rocks.

A scheme for the supply of the Metropolis with water from the upper source of the *WYE*, was projected by Mr. Hamilton Fulton, who proposed to store it in six reservoirs, and to conduct it to London in a conduit 180 miles long.

The *Lug*, one mile above its outfall, receives the *Leddon* on its east bank, which rises near Wolferlow and Thornbury, south of the *Teme* watershed, and flows by Bromyard and Dormington to the *Lug*, draining about 75 square miles of Old Red Sandstone. The *Lug* flows from the north, from Leominster, by Amberley Chapel, Bodenham, and Hampton Park. At Leominster it receives several tributaries, and its valley trends north-westward.

LEOMINSTER.—*Acres*, 8303; population, 6042; constant supply of 120,000 gallons from a well, and catchwaters in the valley above the well; rateable value, 32,578*l.*; Local Government Act, 1858. Rainfall in 1879, at 240 feet above the sea, 30·20 inches; in 1880, 33·45 inches.

Northwards from Leominster, a canal connects this basin with that of the *Teme*.

At Aymestry the *Lug* Valley leaves the Old Red and enters the Upper Silurian tract, and trends westwards to Presteign, where a north-easterly fault with a westerly downthrow has let down a tract of Old Red Sandstone, 2 or 3 miles in width, resting on the Ludlow rocks, over which the stream flows from north-west to south-east from its source west of Heyhop, near the point where the London and North-Western Railway crosses the *WYE* basin into that of the *Teme*.

At Leominster the *Lug* receives the *Arrow*, 26 miles in length, rising in the Upper Silurian country of Llanbedr, south of Builth, and only 2 miles from the course of the *WYE*, between Builth and Talgarth. The *Arrow* receives a tributary at Newchurch, and then enters the Old Red Sandstone, over which it flows, by Kington, and Pembridge, to Leominster.

KINGTON (Herefordshire).—Population, 2075; reservoir of Waterworks Company; supply partly from river, public spring called Crooked Well, and pumps; rateable value, 15,696*l.* 5*s.* Rainfall in 1879 at Lynhales, 35·74 inches, 39·81 in 1880.

A small sub-tributary joins the *Arrow* near its outfall, rising near Weobley, and draining entirely an Old Red Sandstone area.

The valley of the *WYE* from the infall of the *Lug* winds to a much less extent, and changes its direction to west-north-west, by Hereford and Whitney, when it trends to the south-west by Hay to near Talgarth, where it again strikes north-west by Builth and Rhayader, to its source near Llangurig, west of Llanidloes, at a point only a dozen miles from the sea-coast north of Aberystwyth.

The *Arrow* drains so much of the country lying north of the *WYE* that no important tributaries fall into the river's left bank between Hereford and Builth, immediately south of which the *Edw*, 7 miles in length, comes in, draining the Silurians around Llansaintfread.

At Disserth, north of Builth, the *Ithon* joins the *WYE*. This stream is 29 miles in length, rising on the Denbighshire Grits, near Llanbadarn-fynydd, flows south to the infall of the *Aran*, the south-western trend of which it assumes, receiving on its north bank the *Clywedog*, rising at Abbey Cwm-hir, and the *Dulas* flowing by Nantmel and Llanfihangel-fach, draining the Lower Silurians east of Rhayader. North of the latter place the *WYE* receives the *Afon Marteg*, rising in the Upper Silurian hills near Old Chapel, close to the *SEVERN* watershed.

HEREFORD.—Population, 19,822; constant supply of 500,000 to 800,000 gallons, from River *WYE*, stored in a reservoir and filtered; rateable value, 82,000*l.*; Hereford Improvement Act, 1854. Rainfall in 1879, at Burghill, 275 feet above the sea, 28·91 inches; in 1880, 29·89 inches.

HAY (Brecknockshire).—*Acres*, 289; population, 1915;

constant supply from reservoir in the parish, collecting springs; rateable value, 5093*l.*; Company under Joint Stock Act, 1856.

BUILTH.—*Acres*, 2192; population, 1424; supply 20,000 to 30,000 gallons from reservoir, collecting two springs; rateable value, 4573*l.*; Public Health Act, 1858.

River Elan.

On the eastern slope of the central Welsh watershed rise several tributaries of the *WYE*, falling into the stream on the western or right bank. The River *Elan* is 14 miles in length, receiving on its north side a large number of feeders, draining from north to south, over Lower Silurian rocks, until it is joined by the *Afon Claerwen*, rising on the opposite side of the central watershed, to the source of the *TOWY*. It is noticeable that a large number of rivers in the Silurian area, on receiving a tributary, change their direction, and assume that of the stream of the lesser volume. This is the case in the present instance, the north-east trend of the *Claerwen* being continued by the *Elan*.

At Builth the *WYE* receives the waters of the *Yfron*, 21 miles in length, rising on the central watershed, and flowing south-south-east to Llanwrtyd, where it turns abruptly at a right angle eastwards to Builth, the London and North-Western Railway following its valley. A large number of small streams flow in on the north bank, but there is a remarkable absence of tributaries on the south side, the watershed of the *USK* running parallel and close to the stream to Builth, and then to the *WYE* as far as Talgarth.

River Monmow.

Eastward of Talgarth, a tract of country drained by the *Monmow* intervenes between the *WYE* and the *USK*. This tributary is 28 miles in length, rising near Hay on the *WYE*, flows south-east entirely over Old Red Rocks, by Turnastone, Ewyas, Kentchurch, Grosmont, Llanrothall, and

Rockfield, to Monmouth, where it joins the *WYE*, which here assumes its south-eastward direction.

RIVER USK (CXXIV.).

This river has a length of 65 miles; area 540 square miles, of which about 15 square miles consist of Carboniferous Limestone, and about 30 of other Carboniferous rocks, chiefly workable Coal Measures; 495 consist of Old Red Sandstone and Upper Silurian, the latter occupying only a very few miles of the watershed above the sources of the *USK*, which drains a fan-shaped area, rising on the slopes of Mynydd Bwlch-y-Groes, and uniting at Brecon. A Silurian inlier also occurs near the mouth of the valley between Usk and Pontypool, consisting of Wenlock and Ludlow rocks.

South of Brecon, the watershed separating this basin from the streams flowing across the South Wales Coalfield traverses the swelling hills of the Old Red Sandstone, running roughly parallel to the outcrop or escarpment of the Carboniferous Limestone; north of Merthyr Tydvil the latter trends northward, and nearly reaches the *USK* at Crickhowel; the watershed ascends the escarpment, and passes on to the Coal Measures, still running parallel to the strike of the escarpment, but traversing the dip side of it instead of the outcrop, which, however, it crosses west of Caerleon.

Caerleon.—*Acres*, 2327; population, 1099; supply from private wells; rateable value, 4470*l.* 10*s.* Rainfall in 1879, at Llansoar, 82 feet above Ordnance Datum, 53·12 inches; in 1880, 40·13 inches.

Newport.—*Acres*, 2754; population, 35,382; supply constant of 1,500,000 gallons from reservoirs at Yxoysbro, constructed in 1855, holding 80,000,000, and a new one at Pantyress holding 132,000,000; collecting springs and brooks from the Twm Barlom Mountain near Newport; rateable value, 145,611*l.*; works carried out under the Newport and Pillgwenlly Waterworks Act, 1854 and 1872. They supply Christchurch, *acres*, 232; population, 2408; rateable value, 9063*l.*; supply partly from Eve's Well, never dry. Rainfall

in 1879, at Gold Tops, 90 feet above the sea, 46·26 inches; in 1880, 40·90 inches.

Pontypool.—*Acres*, 800; population, 5244; constant supply from reservoir of Pontypool Gas and Water Company; rateable value, 12,677*l.*

Upper Llanfrechfa.—*Acres*, 2250; population, 4177; supply from the Pontypool Company, rateable value, 11,308*l.*, who supply Abersychan, *acres*, 10,000; population, 15,000; rateable value, 36,132*l.* Rainfall in 1879, at Llanfrechfa Grange, 326 feet above Ordnance Datum, 53·12 inches; in 1880, 43·70 inches.

Usk.—*Acres*, 405; population, 1470; supply from springs only; rateable value, 4842*l.*

Abergavenny.—Population, 7285; supply from mountain springs yielding 200,000 gallons; rateable value, 14,300*l.*; works carried out under Abergavenny Improvement Acts, 1854, 1860, and 1871. Rainfall in 1879, at Larchfield, 220 feet above the sea, 38·83 inches; in 1880, 39·47 inches.

Blaenavon.—*Acres*, 3362; population, 9452; supply constant from reservoir storing mountain springs, filtered; rateable value, 24,285*l.* 2*s.* 6*d.*

Abertillery.—*Acres*, 14,000; population in 1881, 6000; supply from reservoir, quality good; works in hands of a Company, which the Urban Sanitary Authority wish to purchase.

Panteg.—Population, 3321; supply from well and springs; rateable value, 14,018*l.*

Brecon (or Brecknock).—*Acres*, 2614; population, 6372; supply 15 to 30 gallons a head, from a reservoir storing water from a mountain stream; rateable value, 15,470*l.*; Local Government Act, 1858. Rainfall in 1879, at 437 feet above Ordnance Datum, was 43·73 inches; in 1880, 48·87 inches.

Brynmawr.—*Acres*, 1170; population, 5344; supply 57,000 to 93,000 gallons daily; stored in reservoir collecting rainfall, conveyed by catchwaters from a drainage area on high hill away from habitations; rateable value, 5197*l.*; works carried out under Public Health Act, 1848.

RIVER EBWY (CXXIII.).

The length of this river is 19 miles; area, 94 square miles, of which 10 are Old Red Sandstone, 1 Carboniferous Limestone, and 83 Coal Measures and Millstone Grit. The *EBWY* and its tributary the *Sirhowy*, 17 miles in length, rise at the top of the Carboniferous Limestone escarpment north of the Coalfield, cross the Coal Measures, and, uniting west of Henllys, again intersect the escarpment, and pass over the Old Red Sandstone to the Bristol Channel.

Tredegar (Monmouth).—*Acres*, 4316; population, 17,951; the Tredegar Iron and Coal Company is empowered to give additional supply to local springs now used to the extent of 80,000 gallons per day, with surface waters stored in a storage and service reservoir and filtered. Rainfall in 1879, at Bedwellty House, 972 feet above Ordnance Datum, 56·99 inches; in 1880, 65·37 inches.

Ebbw Vale.—Population in 1881, 15,519; constant supply from a reservoir storing water from Ebbw; rateable value, 26,384*l.* Rainfall in 1879, at 918 feet above Ordnance Datum, 63·70 inches; in 1880, 59·82 inches.

Rhymney.—*Acres*, 1890; population, 8659; supply, 4 gallons per house, from reservoir 2 miles distant, storing 10,000,000 gallons; rateable value, 16,067*l.* 15*s.*

RIVER RUMNEY (CXXII.).

The length of this river is 22 miles; area, 94 square miles, of which 36 are Old Red, 5 are Carboniferous Limestone, and 53 Coal Measures and Millstone Grit. Like the *EBWY* it rises on the northern Carboniferous escarpment, traverses the Coalfield, and passes on to the Old Red fringing the mouth of the *SEVERN*.

RIVER TAFF (CXIX.).

The length of this river is 25 miles; area, 198 square miles, of which 30 consist of Old Red, 17 of Carboniferous

Limestone, and 147 of Coal Measures and Millstone Grit Trias. The *Taf-fawr* and *Taf-fechan*, each 11 miles long, rise in the Old Red Sandstone country south of the valley of the *USK*, cross the Carboniferous Limestone and Millstone Grit escarpment, and unite between Cyfartha and Merthyr Tydvil; thence the stream continues to flow south, down the dip of the Coal Measures, and maintains the same direction after it has crossed the synclinal axis which traverses the South Wales Coalfield from east to west, consequently flowing up the dip, and passing continually over higher and higher beds, until the Limestone and Old Red are again reached. Two important tributaries, the *Rhondda Fawr* and *Rhondda Fach*, fall into the main stream at Newbridge; they entirely drain a Coal Measure tract.

Cardiff.—Population, 85,378; supply, 2,000,000 gallons, raised into service reservoirs by water power from storage reservoir holding 80,000,000 gallons; the water is derived from two sources, (*a*) streams from gathering ground, (*b*) well and adit, supplied partly by infiltration from the river *ELY*, and partly by the interception of the natural springs; rateable value, 351,000*l.*; Cardiff Waterworks Acts, 1851–1853, 1860, and 1878. Rainfall in 1879, at Pentyrch, 100 feet above the sea, was 52·54 inches; in 1880, 41·80 inches. Rainfall at Cardiff Castle:—

1878.	1879.	1880.
47·34	44·40	37·43

In August, 1878, no less than 10·75 inches fell, while in the same month in 1880 there was only a fall of 0·40 inch.

Llandaff.—[No information.]

Pontypridd.—Population, 12,317; supply obtained from *Mardy*, at the top of the Rhondda Fach Valley, 9 miles distant, and reservoir storing springs near the town; rateable value, 39,000*l.*; Pontypridd Waterworks Company's Acts, 27 & 28 Vict. c. 36; 38 Vict. c. 43.

Ystradyfodwg.—*Acres*, 19,591; population, 55,617; supply of 146,450 (?) gallons from Rhondda Fawr River and the

Ffynnon Gwynon, Nantbwch; rateable value, 141,000*l.*; Ystrad Gas and Water Acts, 1860 and 1874.

Mountain Ash.—*Acres*, 3026; population, 10,289; constant supply from Messrs. Nixons, Taylor, and Cory's reservoir; rateable value, 33,430*l.* 10*s.*

Merthyr Tydvil.—*Acres*, 17,700; population, 48,857; supply from the highest part of the River *TAFF*, Fechan, in the county of Brecon, where the river drains 4000 acres on the Old Red Sandstone; the yield is from 1,200,000 to 2,211,000 gallons per day; there is a storage reservoir on the river holding 396,615,842 gallons, a covered reservoir with filter-bed at Merthyr, and a covered reservoir at Dowlais for supply of that district; the rateable value is (exclusive of Cefn), 131,063*l.*; the works are carried out by the Urban Authority under the Merthyr Tydvil Water Acts, 1858, 1865, and Provisional Order, 1876, to enable the Authority to put in force the compulsory clauses of the Lands Consolidation Acts, 1845, 1860, and 1869. Rainfall in 1879, at 550 feet above Ordnance Datum, 57·89 inches.

Aberdare.—*Acres*, 15,127; population, 33,796; supply 345,000 to 690,000 gallons from *Dare* and *Nanthir* streams, impounded and filtered; rateable value, 129,789*l.* 10*s.*; works carried out under Aberdare Local Board Waterworks Act, 33 & 34 Vict. c. 43. Rainfall in 1879, at 735 feet above the sea, 76·82 inches; 1880, 84·79 inches; at Mardy, 431 feet above Ordnance Datum, 56·02 inches; in 1880, 56·03 inches.

RIVER ELY (CXXI.).

This river has a length of 17 miles; area, 81 square miles. This stream rises on the Coal Measures, south of the central synclinal axis, and flows up the dip on to older rocks, more or less covered with Secondary rocks, resting unconformably upon them. Old Red Sandstone occupies 6 square miles, Carboniferous Limestone 4, Coal Measures 12, and Triassic rocks 59.

Penarth. — Population, 6054; supply under Cardiff Waterworks Acts, 1853, 1860; pumped from River *ELY*

and *Llanisbeen* Brook, and stored in reservoirs and filtered; rateable value, 32,115*l.* 13*s.*

CATCHMENT BASIN CXX.

Area, 67 square miles, 10 of which are Old Red, 15 are Carboniferous Limestone, 5 are Trias, and 37 Lias. This basin includes the larger portion of the Vale of Glamorgan. In it is Cowbridge.

Population in Severn Group of River Basins.

Counties.	Population.	Density, Acres to Persons.	Proportion of Population, probably living in this Group.	Population, about.
In Census of 1871.				
Gloucester	534,320	1·5	$\frac{3}{4}$	400,740
Warwick	633,902	0·8	$\frac{1}{3}$	233,902
Staffordshire	857,333	0·8	$\frac{1}{10}$	85,733
Worcestershire	338,848	1·3	All	338,848
Shropshire	248,064	3·3	$\frac{19}{20}$	235,661
Montgomery	67,789	7·1	$\frac{9}{10}$	61,011
Radnor	25,428	10·0	All	25,428
Brecknock	59,914	7·8	$\frac{19}{20}$	56,917
Hereford	125,364	4·1	All	125,364
Monmouth	195,391	1·8	All	132,003
Glamorgan	396,010	1·3	$\frac{1}{3}$	131,003
In Census of 1881.				
Gloucester	572,480	1·4	$\frac{3}{4}$	429,364
Warwick	737,188	0·7	$\frac{1}{3}$	245,729
Staffordshire	981,385	0·7	$\frac{1}{10}$	98,138
Worcestershire	380,291	1·2	All	380,291
Shropshire	247,993	3·4	$\frac{19}{20}$	235,594
Montgomery	65,798	7·3	$\frac{9}{10}$	59,219
Radnor	23,539	11·6	All	23,539
Brecknock	57,735	7·9	$\frac{19}{20}$	54,809
Hereford	121,042	4·4	All	121,042
Monmouth	211,374	1·6	All	211,374
Glamorgan	511,672	1 0	$\frac{1}{3}$	170,557

CHAPTER XXV.

SOUTH WALES STREAMS DRAINING INTO THE BRISTOL CHANNEL.

RIVER OGMORE (CXVIII.)

Has a length of 16 miles; area, 114 square miles, of which 7 are Carboniferous Limestone, 90 Coal Measures and Millstone Grit, 7 Trias, and 10 Lias. Its tributary, the *Llynfi*, is 10 miles long.

Bridgend.—*Acres*, 629 ; population, 3600; supply partly from Gas and Water Company, and partly from rain-water tanks; rateable value, 8953*l.*; Bridgend Gas and Water Act, 1869, and Provisional Order, 1875.

Masteg.—*Acres*, 6180; population, 7990; supply from springs led through earthenware pipes, 30,000 gallons; rateable value, 23,000*l.*

RIVER AFON (CXVI.)

Has a length of 12 miles; area, 87 square miles, of which 3 consist of Carboniferous Limestone, 75 of Coal Measures and Millstone Grit, chiefly the latter, 5 of Trias, and 4 of Lias. The stream rises near the synclinal axis in the Coalfield and flows up the dip, over higher and higher strata.

Aberavon.—Population, 3396; supply from tanks on mountain-side; reservoir to hold 4,500,000 constructing; rateable value, 8320*l.* 14*s.*

RIVER NEATH (CXVI.).

The *NEATH* is 12 miles long; area, 118 square miles, of which 4 are Old Red Sandstone, 6 Carboniferous Limestone, and 108 Coal Measures and Millstone Grit, chiefly the latter.

This stream also rises in the Coalfield near the synclinal axis, and flows up the dip of the strata to Swansea Bay.

NEATH.—*Acres*, 1427; population, 10,447; supply constant, 360,000 to 390,000 gallons a day, from 3 reservoirs 180 feet above the centre of the town, storing water from streams flowing off the Gnoll Estate, Neath, of 800 acres; rateable value, 31,298*l.*; works carried out under Neath Water Supply Acts, 1861, 1865, and Provisional Order, 1876; extra filter-beds are required. Rainfall in 1879, at 240 feet above the sea, 53·21 inches; in 1880, 48·53 inches; at Glyncorrwg, at 730 feet above the sea, 81·44 inches in 1879, 81·08 inches in 1880.

BRITON FERRY.—*Acres*, 679; population, 5998; supply from Neath and a reservoir at Briton Ferry used for flushing sewers only; rateable value, 13,600*l.*

RIVER TAWE (CXV.).

The length of this river is 26 miles; area, 106 square miles, of which 8 consist of Carboniferous Limestone, and 98 of Coal Measures and Millstone Grit, chiefly the former. This stream, like the *NEATH*, rises in the Black Mountain, forming the watershed between the *USK* Basin and the South Wales Coalfield; like it, flows down the dip of the strata, and, crossing the axis, flows up the dip, to Swansea Bay.

SWANSEA.—Population, 63,739; intermittent supply from intercepting reservoirs on Rivers *Lliw* and *Blaenant Ddu*, yielding 1,500,000 gallons daily; rateable value, 191,000*l.*; works carried out under Swansea Waterworks Acts, 1860 and 1873.

OYSTERMOUTH.—*Acres*, 2615; population 3485; supply from springs and wells; company forming; rateable value, 10,697*l.* 11*s.*

O.S. CATCHMENT BASIN CXIV.

Peninsula of Gower streams; area, 66 square miles, of which 14 are Old Red Sandstone, 29 Carboniferous Lime-

stone, and 23 Coal Measures and Millstone Grit, chiefly the former.

RIVER LLWCHWR (CXIII.).

The length of this river is 16 miles; area, 156 square miles, of which 2 are Carboniferous Limestone, and the remainder Coal Measures and a small tract of Millstone Grit. The source of the main stream is at foot of the Mountain Limestone escarpment above Llan-de-bie, where considerable underground streams were met with in excavating the quarries, which emerge in springs on the slope below. Near Bettws the *LLWCHWR* receives the River *Amman*, 9 miles in length, and flows past Llanedy and Llangennych to the sea at Castell Llwchwr. West of the river another tributary, the *Dafen*, 6 miles long, falls directly into the tidal estuary at Llanelly.

Llanelly.—*Acres*, 2000; population, 19,655; supply from reservoirs storing the *Trebeddod* stream and the River *Lliedi;* rateable value, 50,397*l.*; works carried out under Public Health Act, 1848; Local Government Act, 1858; and the Llanelly (Local Board) Waterworks Act, 1865.

RIVER GWENDRAETH FAWR (CXII.).

This river is 15 miles long; area 73 square miles, of which 30 square miles are Old Red Sandstone, 10 Carboniferous Limestone, and 33 Coal Measures with a small tract of Millstone Grit. The northern watershed runs along the crest of the Old Red hills lying north of the Coalfield, and is carried by them to the sea between estuaries of this river and the *TOWY.* In this basin are Llandyfaelog, Llangynden, Llanddarog, and Kidwelly, where it is joined by the *Gwaendraeth Fach*, also 15 miles in length.

RIVER TOWY (CX.).

The length of this river is 58 miles; area, 514 square miles, of which 42 miles consist of Old Red Sandstone, more or less permeable, and the remainder of Silurian rocks. The

stream rises in the mountains forming the boundaries of Cardiganshire, Radnorshire, and Brecknockshire, flows over Lower Llandovery and Bala Beds, receives on its west bank the *Camddwr* falling in above Capel Ystrad, the *Cothi*, 9 miles in length above Llandovery, whence it follows the strike of the Lower Llandovery and Llandilo beds past Llangadoc, Llandilo, and Llanarthney, when another River *Cothi* falls in on the west bank; it rises within three-quarters of a mile of the other, flowing past Llan-y-Cowys, Llansawyl, Abergorlech, Brechfa, entirely over Lower Silurian rocks. From the infall of this stream to Carmarthen, the *TOWY* continues to follow the strike of the rocks, but the uncomformity between the Upper and Lower Silurian causes the latter to be entirely concealed by the Old Red Sandstone which rests at its outcrop on the Lower Silurian.

From Carmarthen the river trends south-west, and flows down the dip of the Lower Silurian and Old Red, in which it has cut a broad estuary continuous with the estuary of the *TAFF* at Laugharne. The eastern watershed commences on the sea-coast between Kidwelly and the estuary at the top of the Old Red, and passes across that formation until it reaches its base east of Carmarthen, which it follows to the point south of Llandilo, where the Old Red has its narrowest outcrop, one mile and a quarter; then it again passes to the top of the Old Red near the source of the *USK;* then trends northwards, passing over the Old Red, Ludlow, Wenlock, Tarannon, and Lower Llandovery rocks. The western watershed also traverses Old Red Sandstone at its commencement on the sea-coast between the *TAFF* and the *TOWY*, but only for 3 miles; the whole of its course to the point where it meets the eastern watershed is over Lower Silurian rocks. The slope from the western watershed is a distance of 12 miles, while the eastern slope is only on an average 5 or 6 miles, and often less than 2; which sufficiently explains the chief tributaries being all on the west bank.

Llandilo.—*Acres*, 300; population, 1533; supply con-

stant from reservoir storing springs; rateable value, 4615*l.*; under 11 & 12 Vict. c. 63. Rainfall in 1879, at Dynevor Castle, 236 feet above the sea, 47·03 inches; in 1880, 52·31 inches.

Llandovery.—Population, 2035; supply from wells; rateable value, 1861*l.* Rainfall in 1879, at 217 feet above the sea, 47·95 inches; in 1880, 50·09 inches.

Carmarthen.—Population in 1881, 10,512; supply intermittent of 200,000 gallons from two catchwater reservoirs, holding 11,000,000 gallons, being 50 days' supply; rateable value, 33,622*l.*; Public Health Acts, 1841 and 1875. Rainfall in 1879, at the Joint County Asylum, 189 feet above the mean sea-level, 49·78 inches; in 1880, 43·60 inches.

RIVER TAFF (CIX.).

The length of this river is 12 miles; area, 183 square miles, of which about 10 are Old Red Sandstone, on the coast margin, and the rest Lower Silurian rocks of very impermeable kinds. At Lampeter, near the western watershed, a considerable exposure of Llandilo Limestone occurs. The central Welsh watershed forms the northern limit of this basin; near its western limit rises the *TAFF*, then the *Afon Gynin*, 8 miles in length, the *Dewy Fawr* which unites with the last after flowing 12 miles, and falls into the *TAFF* at St. Clare, then the *Cywyn*, 11 miles in length, with a feeder from the east rising near Carmarthen.

O.S. CATCHMENT BASIN CVIII.

Area, 61 square miles. The headlands lying between Carmarthen and St. Bride's Bays are traversed by a series of sharp anticlinal and synclinal folds, running in an east-south-east direction. To the north is a coalfield, overlapping the Lower Carboniferous rocks westwards, and resting directly on the Lower Silurian at Haverford West, flanked by Upper Silurian and Intrusive Porphyry between St. Bride's and Milford, and Millstone Grit, Carboniferous Limestone, and

Old Red at Tenby, between which and St. Gowan's Head are two anticlinals, that of Cheriton bringing the Ludlow rocks to the surface. The peninsula between St. Gowan's Head and St. Bride's is deeply indented by Milford Haven, which is a long fiord running nearly with the strike of the Old Red for 12 miles, and then turns northwards extending into the centre of the Coalfield, where it receives the waters of the *CLEDDAU*, draining a Cambrian and Lower Silurian area, and rising within 2 miles of the St. David's Head coast-line. Silurian, 3 square miles; Old Red Sandstone, 27; Carboniferous Limestone, 13; Carboniferous rocks, chiefly Coal Measures, 18 square miles.

Tenby.—Population, 4783; supply varies from 80,000 to 200,000 gallons, winter average 150,000 gallons; a well called Ladywell is stored in a service reservoir, partly fed by a gathering-ground, also a storage reservoir filled from adit driven in hill, and its natural drainage; rateable value, 18,256*l.*; Public Health Act.

O.S. CATCHMENT BASIN CVII.

Area, 114 square miles. This area is drained by Milford Haven, which is the tidal portion of the *CLEDDAU*, 212 square miles in extent, or with Milford Haven, 326 square miles. Its structure has already been described: 161 square miles consist of pre-Cambrian, Cambrian, and Silurian rocks of impermeable character, all lying north of the Coalfield, with the exception of the narrow belts of Upper Silurian brought up by anticlinals in the Old Red, which occupy 78 square miles, which is overlaid by the Carboniferous Limestone extending over 25 square miles, which is partly overlapped by the Coal Measures, 62 miles in extent, resting on the Lower Silurian east of St. Bride's Bay.

Pembroke.—*Acres*, 4376; population, 14,197; an Act for supplying this town was passed, 9 Geo. 4, and received royal assent 15th July, 1828; under it a reservoir was constructed, supplying 35,000 gallons a day. Pembroke Dock is supplied

by distinct reservoirs belonging to the Government, and public springs yield 6000 gallons; rateable value, 30,573*l.*

MILFORD.—*Acres*, 667; population, 3813; constant supply of 15,000 to 30,000 gallons, raised by force-pumps from springs to reservoir; rateable value, 7054*l.*; works under 20 & 21 Vict.; the Milford Improvement Act, 1857.

ST. BRIDE'S BAY STREAMS (BASIN CV.).

Area, 65 square miles, of which Lower Silurian, and older rocks occupy 52 square miles, Old Red Sandstone, 3; and Coal Measures, 10; the latter rest on the Lower Silurian on the north side of the Bay; and on the south side are in contact with Intrusive Felspathic Porphyry, on the southern side of which is the Old Red Sandstone, the Coal Measures having overlapped the Carboniferous Limestone.

POPULATION of SOUTH WALES STREAMS DRAINING into BRISTOL CHANNEL. In CENSUS of 1871.

COUNTIES.	Population.	Density, Acres to Persons.	Proportion of Population probably living in this Group.	Population, about
Glamorgan	396,010	1·3	$\frac{2}{3}$	265,007
Brecknock	59,914	7·7	$\frac{1}{20}$	2,995
Carmarthen	116,944	5·1	$\frac{9}{10}$	105,250
Pembroke	91,936	4·3	$\frac{9}{10}$	82,743
In CENSUS of 1881.				
Glamorgan	511,672	1·0	$\frac{2}{3}$	341,115
Brecknock	57,735	7·9	$\frac{1}{20}$	2,886
Carmarthen	124,861	4·8	$\frac{9}{10}$	111,375
Pembroke	91,808	4·2	$\frac{9}{10}$	82,628

CHAPTER XXVI.

THE WEST WALES STREAMS.

WEST WALES. *Sea-coast:*—St. David's Head, Pembrokeshire, to Carmel's Point, Anglesea.

The Central Welsh watershed runs from headland to headland, in a semicircle, the centre of which is a point in the sea, 8 miles south-west of Bardsea Island, and equidistant from the two capes; the coast-line runs roughly parallel to the watershed, but its uniformity is broken by the peninsula jutting out between Carnarvon and Cardigan Bays, and the curve is flatter than a semicircle, the mouth of the River *DOVEY* being only 40 miles distant from the point in the sea which is the half-diameter of the distance from Carmel's Point to St. David's Head, 100 miles apart. The watershed from point to point is about 170 miles in length, traversing pre-Cambrian, Cambrian, and Lower Silurian Rocks throughout, with the exception of 15 miles' range of Upper Silurian, near Dinas Mowddwy, above the source of the *SEVERN*, which are brought in by a south-south-east synclinal axis, ranging from Gaerau Crwyr to Carrig Hir. The average distance from the watershed to the sea-coast is 15 miles, and around Plynlimmon and northwards the river runs straight down the slope to the sea. Southwards the River *TEIFI* runs with the strike of the rocks, and parallel to the watershed, until it falls into the sea at Cardigan. The northern boundary of this basin is a secondary watershed, merging into the central one south of Plynlimmon; west of it the streams run direct to the sea.

The NEVERN (CIV.).

The length of this river is 9 miles; area, 94 square miles of impermeable pre-Cambrian, Cambrian, and Lower Silurian rocks. It rises on the opposite side of the central watershed to the *CLODDEW* River; on the southern margin of the estuary is Newport, west of Dinas Head; another stream falls into the sea, at Fishguard, rising east of Llanychllwyddog; west of Strumble Head another stream flows past St. Nicholas.

The TEIFI (CIII.).

The length of this river is 55 miles; area, 386 square miles; rises at Yspytty Ystwyth, 13 miles from the sea; the watershed between it and *Ystwyth* River is crossed by the Aberystwyth and Carmarthen Railway at Ystrad Meurig. It flows past Tregaron, Bettws Bledrws, and Lampeter, below which point it is navigable, thence, by Langeler and Newcastle Emlyn, to Cardigan.

CARDIGAN. — *Acres*, 4043; population, 3633; constant supply from reservoir, storing springs; rateable value, 7880*l.* 11*s.*; works carried out under Market and Improvement Act, 1857.

LAMPETER. — *Acres*, 1570; population, 1443; constant supply, except in drought, from reservoir storing springs, near Troedyrhiw, about a mile distant; rateable value, 2580*l.* A larger reservoir is required.

West of the western watershed of the *TEIFI* are three small basins draining directly to the sea.

CATCHMENT BASIN CII.

Area, 48 square miles, includes villages of Llanarth and Henfynyw and Local Authority of New Quay; *acres*, 640; population, 1449; supply from rain-water cisterns only; rateable value, 1140*l.*

RIVER AERON (CI.).

Fifteen miles in length, with an area of 52 square miles, rising north of Llan Penal, and falling into the sea at Aberafron.

RIVER ARTH (C.).

Six miles long, with an area of 31 square miles, rising west of the last basin, including within its bounds the village of Llansantffraid.

The WYRAL (XCIX.).

Eight miles in length, rising near Llangwryfon, with an area of 23 square miles, including the *Carrog*, 8 miles in length, rising near Llanddeiniol.

The YSTWYTH (XCVIII.).

Length, 16 miles; area, 75 square miles; the eastern margin is the central Welsh watershed, immediately above the source of the *WYE*. The railway from Lampeter, which follows the *TEIFI* valley, crosses the watershed, and follows this stream to the sea, near Aberystwyth.

The RHEIDOL (LXXXII.).

Length, 20 miles; area, 70 square miles; rises between Mynydd Bach and Plynlimmon, and flows south with the strike of the beds to south of Yspytty Cynfyn, when it turns abruptly west, and flows to Aberystwyth, where it is joined by the *YSTWYTH*, and the united streams fall into the sea.

Aberystwyth.—*Acres*, 800; population, 6664; at present intermittent supply of 160,000 gallons, from reservoir storing springs. Scheme now being carried out by Mr. Stooke, C.E., of Shrewsbury, tapping the head springs immediately below the crest of Plynlimmon. Rainfall in 1879, at Goginan, 290 feet above the sea, 48·02 inches; in 1880, 47·46 inches.

The country west of the *RHEIDOL* does not drain into

that stream, but directly into the sea, a secondary watershed separating it from the two following basins :—

CATCHMENT BASIN LXXXI.

This area is 24 square miles in extent, and is drained by two streams, flowing directly west.

RIVER LERY (*LXXX.*).

This river is 10 miles long, and drains 34 square miles. It drains, with two other small streams included in this basin, into the estuary of the River *DOVEY*. Llanfihangel is the principal village.

RIVER DOVEY (*AFON DYFI*) (*LXXIX.*).

Length, 19 miles; area, 217 square miles, near to the *TEIFI;* this is the most important basin in West Wales. The central Welsh watershed separates its head waters from those of the *DEE* and the *SEVERN;* the railway between Machynlleth and Newtown passes over into the latter valley, between Llanbrynmair and Carno. This portion of the *DOVEY* basin is drained by the *Afon Twymyn*, 7 miles in length, flowing west, by Darowen to the main stream, which rises at Llan-y-Mowddwy, at a point only 3 or 4 miles distant from the sources of the *DEE* and the *Vyrnwy;* thence it flows south-west by Dinas Mowddwy, Mallwyd, Cemmaes, Llanwrin, and Machynlleth, where it receives the *Afon Dulas*, 6 miles in length, on its right bank; thence by Pennal, to the estuary, which extends for 6 miles into the country, and is 1½ mile across at Aberdovey, which is partly supplied with water from a reservoir, and partly by pumps. North of the *DOVEY* the ridge of mountain running parallel to and between the sea-coast and the central Welsh watershed, while it forms the eastern watershed of several of the less important streams, again bounds a basin.

The AFON DYSYMI (LXXVIII.).

This stream is 10 miles long, and drains 64 square miles; it rises on the southern slopes of Cader Idris, which ridge separates this basin from the *AFON MAWDDACH;* thence the river flows, by Llanfihangel and Llanegryn, to the sea, at Towyn, near which it receives on its left bank the *Afon Felindre.*

Towyn (Merionethshire). — *Acres,* 23,291; population, 3363; no public waterworks; supply from springs, wells, and river.

RIVER MAWDDACH (LXXVII.).

Length, 18 miles; area, 151 square miles; the third river in order of importance in West Wales. Its source is in the high ridge of Lower Silurian Volcanic rocks, extending between Penmaen and Moel Llyfnnant, overlooking the valley above Bala Lake. Its western affluent drains the Cambrian rocks of Craig-y-Penmaen, and Llawllech; the central stream follows the strike of the Tremadoc Slates and Lingula Flags, and the eastern margin of the basin is formed by the Volcanic rocks of Cader Idris.

The principal tributaries are all on the west bank, the *Gain* 8 miles in length, and the *Eden* 6 miles: these and another stream all fall into the main stream near the junction of the Cambrians with the Lower Silurians, west of Rhobell Fawr, thence by Llanellyd and Dolgelly, and Capel Arthog, to the sea at Barmouth—*acres,* 776; population, 1200; supply constant of 20,000 gallons from a spring issuing on the hill-side; works carried out under Provisional Order, Local Government Board; rateable value, 4466*l.*

Dolgelly.—Population, 2457; constant supply afforded by a Company from a lake in the hills; rateable value, 5274*l.* Rainfall in 1879, at the National School, 43 feet above the sea, 60·2 inches; in 1880, 60·50 inches; at Brithdir, 465 feet above the sea, 64·31 inches in 1879; and

in 1880, 63·61 inches; at Nannau Park, 690 feet above the sea, 61·67 inches in 1879.

O. S. CATCHMENT BASIN LXXVI., & R. ARTRO (LXXV.).

The Cambrian rocks to the west of the Mawddaels drain directly into the sea; the small stream flowing into the sea near Llanaber forms *BASIN LXXVI.*, and drains 3 square miles. North of it is the basin of *ARTRO,* which flows into the sea at Llandanwg; south of this stream two others flow into the sea; south of Llanddwywe, the eastern margin is the secondary watershed already described, which is interrupted or broken through by the principal streams which rise on the western slope of the central Welsh watershed. The two may be regarded as the crests of two waves, of which the eastern rises to the greater height, though the second attains a great elevation at Cader Idris and Snowdon. The *ARTRO* is 7 miles in length, and drains an area of 45 square miles, entirely consisting of Cambrian rocks.

RIVER PRYSOR (LXVI.).

This river has a length of 11 miles, area 141 square miles, and is the fourth river of relative importance in West Wales. Its head waters rise on the central Welsh watershed, near the sources of the *CONWAY* and the *DEE;* it flows past Trawsfynydd to Maentwrog, where it receives a tributary from Ffestiniog, thence by Llandecyn to a broad estuary called Traeth-bach, on the north shore of which is Tremadoc, Penmorfa; and CRICCIETH; population, 900; Private Waterworks and 2 wells. South of the estuary is Harlech.

An important stream rising on the south-western slope of Snowdon flows by Beddgelert to the estuary at Tremadoc.

The principal feeder rises north-east of Snowdon, at Gorphwysfa, near the 13th milestone from Carnarvon, in the Pass of Llanberis, where also originate the head waters flowing into Llyn Padarn and the basin of the *CONWAY.*

At Cwm Dyli it receives the stream draining the beautiful tarn Glaslyn, lying under the eastern brow of Snowdon, and the fine lake Llyn Llydaw, which Professor Ramsay was the first to describe as fringed with moraine mounds.* It is more than a mile in length, and of green colour, like some of the Swiss lakes. From Cwm Dyli the stream flows through the broad and deep valley of Nant Gwynant (White Vale Valley) into Llyn Gwynant, which formerly extended a mile further up the valley, the lake having silted up at the higher end. At Pen-y-Bryn, near the foot of the lake, the stream draining Cwm-y-Llan falls into this valley. Six principal valleys are formed by the six spurs of Snowdon, each of which Professor Ramsay has shown as filled with ice in the Glacial period. The Cwm Dyli and Cwm Llan glaciers united in Nant Francon, which sweeps south-westwards, and was instrumental in scooping out Llyn Dinas. At Beddgelert the stream turns southwards, and receives an important tributary draining Nant Colwyn.

From Snowdon westwards the northern limit of the *PRYSOR* basin is formed by the secondary watershed, which is continued through the peninsula of Carnarvonshire; south of this ridge are various small streams, which may be regarded as once tributary to the *PRYSOR*, while similarly the streams north of the ridge forming *CATCHMENT BASIN LXII.* originally flowed into a stream that once rose at a point over what is now the Menai Straits, and flowed out into what is now Carnarvon Bay.

DWY-FACH (*LXV.*).

Length, 8 miles; area, 48, with its tributary *Dwy-fawr*, also 8 miles long. This river rises in the Felstones of Llwyd Mawr, and drains sedimentary and igneous rocks of Llandilo age; it flows past Llanfihangel-y-Pennant and Dolbenmaen.

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* 'The Old Glaciers of North Wales,' p. 62.

RIVER ERCH (LXIV.).

Length, 4 miles; area, 35 square miles; the watershed runs parallel to, and hugs the northern coast of the promontory; the country consists of Felstones and Llandilo rocks. The chief town in the basin is PWLLHELI—*acres*, 1176; population, 3006; wells and pumps only; rateable value, 5660*l.* 12*s.* 3*d.* Rainfall at Bodfaen, 80 feet above the sea, 46·78 inches in 1879, and 42·30 in 1880. The villages are Llanbedrog, Bodnan, Llarnen, and Caerynwch.

RIVER SOCH (LXIV.).

Length, 7 miles; area, 33 square miles. The eastern and western margins of this basin are formed by masses of Felstone; the river runs over Llandilo rocks, and does not run directly to the sea at Hell's Mouth, but turns abruptly eastwards to St. Teedwall's Road, south of which the promontory is formed of Cambrian rocks.

ABERDARON STREAMS (LXII.).

About 13 square miles consist of metamorphosed Cambrian rocks, which extend into Bardsey Island.

CATCHMENT BASIN LXII. A.—North of the Carnarvon Minor Watershed.

This group of streams drains into Carnarvon Bay, with an area of about 130 square miles. The peninsula of Carnarvon is called by the Welsh "Lleyn," its coast-line ranges with strike of the rocks north-east from Bardsey. South to Porth Dinlleyn, near Nevin, the rocks are metamorphosed Cambrian, the watershed hugs the coast, and streams are unimportant. The watershed gradually trends more to the east than the coast-line, giving a longer slope to the sea. The first stream draining this tract is the *Llyfni*, 6 miles in length, rising in Llyn-y-Gader, a tarn with two outlets, the

other draining into the River *Gorfai;* the tarn is close to the Carnarvon and Beddgelert Road. Thence it flows into another tarn at the foot of a hill, Clogwyn-y-Gareg, which the stream nearly encircles; thence it flows under Mynydd Mawr; and it passes through another lake, Llyn Nant-y-Llef, past the village of Llanllyfni to the sea, over Cambrian and altered Cambrian rocks.

The source of the *Gorfai* has already been described. It is 10 miles in length, some of its eastern feeders drain the western valley of Snowdon, Cwm-y-Clogwyn, which retains both glacial striæ and glacial moraines. These streams unite and flow through Llyn Cwellyn, which is about a mile in length, and thence by Bettws Garmon to the sea at Llanfaglan, near Carnarvon. Westward of the mouth of the stream is a tract of *blown sand.*

River Seiont.

This stream is 10 miles in length, rising at Gorphwsfa at the head of the Pass of Llanberis, thence it flows in a remarkably straight line north-westwards past Llanberis, through Llyn Peris and Llyn Padarn, to a point between Llanrug and Llanddeiniolen, where it turns at a right angle south-westwards. This valley received at least three glaciers from Snowdon, and others from the valleys north of the pass, which, uniting, scooped out the lakes referred to. The stream in descending passes on to older rocks; rising on the volcanic rocks of the Bala Series, it passes over the Cambrians, in the centre of which is an extensive area of Felstone Porphyry, which is considered by Dr. Hicks to be a pre-Cambrian boss; in any case, it corresponds to an anticlinal in the Cambrians; Llandilo beds coming on again on the Menai Straits side of the mass at Carnarvon.

Carnarvon.—*Acres,* 2400; population, 10,237; constant supply from River *Gwrfai,* 3 miles below Llyn Cwellyn; rateable value, 23,875*l.* 8*s.* 8*d.*; Carnarvon Waterworks Act, 1865. Rainfall in 1879, at Cocksidia, 120 feet above the sea, 38·87 inches; in 1880, 40·26 inches.

Anglesea Streams west of the Central Watershed.

RIVER BRAINT (LX. A).

Length, 4 miles; area, 32, of which altered Cambrians occupy 20, Carboniferous Limestones 10 miles, and Coal Measures 2 miles. Villages in this district are Llangafo, Llanddaniel, and Llanidan.

RIVER CEFNI (LIX.).

Length, 11 miles; area, 41 square miles, of which 32 square miles consist of metamorphosed Cambrian, Cambrian, and Lower Silurian, 6 of Carboniferous Limestones, 3 Coal Measures, and 5 of Permian. In this basin is Llangefni, and the villages of Tregaian, Llanfinnan, and Newborough.

CATCHMENT BASIN LVII.

Area, 69 square miles, all of which consist of Lower Silurian and still more ancient rocks. Holyhead Island is included by the Ordnance Survey in this basin, and consists of altered Cambrian. Holyhead Harbour is situated on the north-east coast of the island, north of the narrow strait separating it from Anglesea. Rainfall at Holyhead in 1879, 44 feet above sea, 33·87 inches.

RIVER ALAW (LVI. A).

Length, 8 miles; area, 36 square miles, all of which are altered Cambrian. The stream rises close to the central watershed near Llanerchymedd. The villages in the basin are Llanfachreth, Llanfaethlu, and Llanfairynghornwy.

Population of West Wales Streams Draining into the Irish Sea. In Census of 1871.

Counties.	Population.	Density, Acres to Persons.	Proportion of Population, probably living in this Group.	Population, about
Pembroke	91,936	4·3	$\frac{1}{10}$	9,193
Carmarthen	116,944	5·1	$\frac{1}{10}$	11,694
Cardigan	73,488	6·0	All	73,488
Montgomery	67,789	7·1	$\frac{1}{10}$	6,778
Merioneth	47,369	7·3	$\frac{2}{3}$	31,582
Carnarvon	106,122	3·4	$\frac{1}{3}$	35,374
Anglesea	50,919	3·8	$\frac{3}{4}$	38,190
In Census of 1881.				
Pembroke	91,808	4·2	$\frac{1}{10}$	9,180
Carmarthen	124,861	4·8	$\frac{1}{10}$	12,486
Cardigan	70,226	6·3	All	70,226
Montgomery	65,798	7·3	$\frac{1}{10}$	6,579
Merioneth	54,793	7·0	$\frac{2}{3}$	36,529
Carnarvon	119,195	3·1	$\frac{1}{3}$	37,375
Anglesea	50,964	3·7	$\frac{3}{4}$	38,223

CHAPTER XXVII.

THE NORTH WALES STREAMS.

East of the Central Watershed, Coast-line Carmel's Point to Point of Ayr.

Anglesea Streams east of the Central Watershed.

CATCHMENT BASIN LVI. B.

Area in this basin, 22 square miles, consisting of altered Cambrian rocks. Its coast-line extends from Carmel's Point to Cemmaes Bay. In this basin are the villages of Llanfechell and Rhosbeireo.

CATCHMENT BASIN LVIII.

Area, 47 square miles, consist of 31 square miles of Lower Silurian, altered, and igneous rocks, 12 square miles of Carboniferous Limestones, and 4 of Permian. The coast-line extends from Hells Mouth to Red Wharf Bay. In the basin is Amlwch, and the villages of Llanwenllwyfo, Llaneugrad, and Penrhos Llugwy.

CATCHMENT BASIN LX. B.

Area, 21 square miles, of which 5 consist of Carboniferous Limestones, and the remainder of Lower Silurian and altered Cambrian rocks. The coast-line extends from Red Wharf Bay to opposite Puffin Island, and then turns abruptly, forming the Menai Straits. In this basin is Beaumaris, and the villages of Llanddona, Llaniestyn, and Llanfaes.

Beaumaris.—*Acres*, 3064; population, 2241; constant supply from Company's reservoirs; rateable value, 831*l.* 7*s.* 9*d.*

Carnarvonshire.

CATCHMENT BASIN LXI.

This basin has an area of 78 miles, consisting of Cambrian and Lower Silurian rocks, associated with contemporaneous volcanic and igneous rocks. The chief stream drains Nant Francon, rising above Llyn Ogwen, between Y Glyder Fawr and Carnedd Dafydd, thence flowing by Bethesda to Bangor.

Bangor.—*Acres*, 1350; population, 8240; constant supply of 30 gallons per head from service reservoir storing water from *Afon Gaseg;* rateable value, 21,815*l.* 3*s.*; Bangor Gas and Water Act.

Bethesda.—*Acres*, 873; population, 6890; reservoir of Local Board, mains of Bangor Gas and Water Company; rateable value, 5747*l.*; Bethesda Improvement Act.

Llanfairfechan.—*Acres*, 2227; population, 2041; constant supply from reservoir storing upland springs, belonging to a Company; rateable value, 7566*l.* Rainfall in 1879, 150 feet above the sea, 32·19 inches.

RIVER CONWAY (LXVII).

The length of this river is 25 miles; area, 222 square miles. The west bank of the river mainly consists of Lower Silurian rocks, the east bank of Denbighshire Grits.

The Cambrian rocks near Bangor consist of fine gritty and slaty beds, purple and grey. They are generally well cleaved, the cleavage faces, or slates, showing a distinct ribboned or banded appearance, caused by bedding, the angle and direction of the bands giving the position of the dip. They are much altered in the Bangor district, and on the Anglesea side of the Menai Straits they assume all the characters of metamorphic rocks, consisting of foliated gneiss, hornblende, and quartz rocks, associated with Greenstone and elvan dykes, and veins and bosses of Granite. These bosses are believed by Professor Ramsay to be the deep-seated melted nuclei from which proceeded the inter-

bedded felspathic lavas and ashes found interstratified with the Bala Beds of Snowdon, Carnedd Dafydd, and the country between Conway and Moel Hebog. Professor Ramsay considers the ash-beds forming the top of Snowdon to be the equivalent of the Bala Limestone. The old lava beds south of Snowdon form one mass, on Snowdon and Y Glyder Fawr; the trap splits into three or four separate beds, which extend from Moel Hebog on the south to Conway on the north.

The *CONWAY* rises in the extreme southern corner of the basin, near the source of the tributaries of the *DEE*, and flows north-east by Yspytty Evan to Pentre Voelas, where it turns abruptly north-westward to Bettws-y-Coed, and then flows northward to the sea at Conway, its estuary lying between Penmaenmawr and the Great Ormes Head.

Penmaenmawr.—[No information.]

Conway.—*Acres*, 3551; population, 3179; supply from reservoir impounding springs and wells, belonging to a Company; rateable value, 12,099*l*.

Ascending the river from Conway, several small tributaries flow in on the west bank north of Llanrwst, and at Bettws-y-Coed the *Afon Llugwy* comes in; it is 6 miles in length, and rises west of Capel Curig, and forms the well-known Swallow Falls.

The watershed between Nant Francon and the *Afon Llugwy* descends from the Glyders, and crosses the broad, deep valley, drained by these two streams, flowing in opposite directions, at the 36th milestone, near Waen Uchaf, and ascends the opposite hill, Craig Llugwy, and thence to the crest of Carnedd Llewellyn. In the south-eastern portion of the mountain is a deep valley, Cwm Llugwy, in which are springs flowing into a moraine-dammed tarn, which is the source of the *Llugwy*.

South of the infall of the *Llugwy* is that of the *Afon Lledf*, which, rising on the watershed above Beddgelert, drains the country around Dolwyddelan for a distance of 7 miles.

O.S. CATCHMENT BASIN LXVIII.

Area, 39 square miles, of which 30 are Upper Silurian, 7 Carboniferous Limestone, and 2 Trias.

The Carboniferous Limestone forms the two fine hills known as the Great and Little Ormes Head. Between these two is an extensive alluvial plain, terminating in the banks of the *CONWAY* to the west, and in the sea to the east, between the two headlands. The town of Llandudno is built partly on the north-western portion of the plain, and partly on the slope of the Great Ormes Head. Between the Little Ormes Head and the hills lying near Colwyn Bay another alluvial plain occurs, connecting the *CONWAY* with the sea at Landrillo-yn-Rhos. It is an area of former obstructed and present artificial drainage, a well-preserved sub-marine forest being still observable at Llandrillo. The level of the highest point of this plain, near the point where it is crossed by the Holyhead Railway, is but a few feet above high-water mark, and, were the alluvium and peat to be removed, there is little doubt the River *CONWAY* would flow into the sea at Llandrillo. That it once did so is stated by old Welsh traditions, as pointed out by Mr. Hall.*

Llandudno.—*Acres*, 2892; population, about 4838; intermittent supply of 13,000 gallons, from reservoirs collecting springs on the hills; rateable value, 35,000*l.*; Under Llandudno Improvement Act, 1876. Rainfall at Warwick House, 99 feet above Ordnance Datum, 29·36 inches in 1879; 35·57 in 1880.

Colwyn Bay.—Is built on a terrace of Upper Boulder Clay and Middle Drift Sand, chiefly on the latter. Rainfall at Nant-y-Glyn, 180 feet above Ordnance Datum, 30·20 inches in 1879, and 38·98 in 1880.

RIVER CLWYD (LXIX.).

The length of this river is 25 miles; area, 319 square miles, of which 201 consist of Upper Silurian, 2 of Old

* Proc. Liverpool Geol. Soc.

Red Sandstone; Carboniferous Limestone, 35; Lower Coal Measures, 10; Trias, 71.

The *AFON CLWYD* rises on the Denbighshire Grit, near Derwen, north of the *DEE* watershed, at Corwen, and flows eastwards and northwards on the Wenlock Shales, in which a broad and deep valley has been excavated, and filled with Carboniferous Limestone, which, in its turn, was considerably denuded before the deposition of the Triassic Lower Mottled Sandstone, which occupies the bottom of the existing valley drained by the *CLWYD*, but is seldom seen, owing to thick deposits of overlying Glacial Drift, consisting of Boulder Clay, resting on Sands and Shingle, and, high up the valley, of Gravelly Clay.

The coast-line of the basin, extending from Abergele to Prestatyn, is a low alluvial tract, with occasional hillocks of Glacial Drift rising above the plain, and fringed with Sand Dunes, rising to a considerable height, east of Rhyl.

ABERGELE and PENSARN.—The population of 7285 is supplied by the Llanefydd and Rhyl District Water Company, which collects surface-water in a reservoir at Llanefydd. Pensarn is built on the alluvial plain close to the sea, and is a mile distant from the old market town of Abergele, built on a terrace of Glacial Drift. Rateable value, 7302*l.* 4*s.*

RHYL.—*Acres*, 600; population, 6034; supply from the Llanefydd watershed reservoir of the *Rhyl Waterworks Company*. The supply is constant and filtered; improved filter-beds are constructing; rateable value, 27,420*l.* 10*s.* The rainfall in 1879, 21 feet above Ordnance Datum, was 28·10 inches; in 1880, 31·72 inches.

PRESTATYN.—Waterworks constructing. Rainfall in 1879 at Nant, 30 feet above the sea, 29·44 inches; in 1880, 33·58 inches.

Ascending the river, the old town and castle of Rhyddlan is passed, and the town and cathedral of St. Asaph, south of which the river receives the *Elwy*, 18 miles in length, rising on the eastern margin of the Conway valley above Llanrwst.

West of Llanefydd, the *Elwy* receives the *Aled*, 5 miles in length, rising in a small lake under the *DEE* watershed, and flowing past Llansannan. The rainfall at Nantllys, St. Asaph, 173 feet above the sea, was 31·28 inches in 1879.

Several small feeders fall in the *CLWYD* on the west bank, between Denbigh and Ruthin; below the former a feeder falls in on the east bank, from the country above Bodvari, through the valley of which the railway has been carried over the watershed to Mold.

DENBIGH.—*Acres*, 8778; population, 6491; intermittent supply of 80,000 gallons, from reservoir impounding springs 3 miles from the town, supplemented by rainfall of upland watershed; water is strained through gravel before entering impounding reservoir, and filtered in service reservoir; rateable value, 26,915*l.*; Denbigh Waterworks Act, 1863.

RAINFALL in 1879 and 1880.

	Feet above the Sea.	Inches. 1879.	Inches. 1880.
At Glan-y-Wern	150	27·66	..
„ Vale, St.	230	33·23	37·23
„ Dyffryn Aled	650	38·04	47·49

RUTHIN.—*Acres*, 4370; population, 3034; constant supply of from 20 to 25 gallons per head from a reservoir, impounding *Plasynant* stream, in parish of Llanfair, 2 miles distant; rateable value, 12,021*l.*; Ruthin Waterworks Act, 1863; *Ruthin Waterworks*, 1877. The reservoir and filter-beds are being doubled.

Population of the North Wales Streams.

In Census of 1871.

Counties.	Population.	Density.	Proportion in this Group.	Probable Population.
Anglesea	50,919	3·8	$\frac{1}{4}$	12,729
Carnarvon	106,122	3·4	$\frac{2}{3}$	70,748
Denbigh	104,266	3·6	$\frac{2}{3}$	69,510
Flint	76,245	2·4	$\frac{1}{10}$	7,624
In Census of 1881.				
Anglesea	50,964	3·7	$\frac{1}{4}$	12,741
Carnarvon	119,195	3·1	$\frac{2}{3}$	81,820
Denbigh	108,931	3·1	$\frac{2}{3}$	72,621
Flint	80,373	2·1	$\frac{1}{10}$	8,037

CHAPTER XXVIII.

THE CESTRIAN BASIN.

RIVER DEE (*LXX.*).

Coast-line, Point of Ayr, North Wales, to Hoylake, Cheshire.

THE length of this river is 70 miles; area, 813 square miles, of which Silurians occupy 380, Carboniferous Limestone, 30; Carboniferous rocks, including Coal Measures, 132; Permian, 22; and Trias, 279.

This basin includes the greater part of the counties of Merionethshire, Denbighshire, Flintshire, and parts of Shropshire and Cheshire. It will be convenient to describe the western area first, which drains into the tidal estuary between Chester and the *CLWYD* watershed.

Estuary—Left Bank.—The more valuable coal seams of the Flintshire Coalfield belong to the lower portion of the Middle Coal Measures, resting sometimes unconformably on the Lower Coal Measures, with Gannister coal seams and rock, which, in the Holywell district, rest conformably on Black Shales with Cement Stones, resting on Black Chert, long worked in the district for the supply of the Staffordshire potteries with silica, forming the top of the Carboniferous Limestone. The dip of the Measures is towards the river, at a steep angle, and the beds of sandstone occurring in the Middle Coal Measures absorbing much rainfall at the outcrop, cause the mines in the deep valley along the course of the *DEE* to be heavily watered, which, coupled with the intensely faulted character of this Coalfield, renders coal-mining here somewhat precarious.

At Mostyn the Coal Measures crop to the surface, but in some parts of Mostyn Park are overlaid by Boulder Clay,

on which an impounding reservoir has been constructed for the supply of the Hall and village. In the colliery village, south of the ironworks, sanitary arrangements are very bad, and the water-supply is only obtained by carrying water from a spring near the church.

Holywell.—Population, 3091; no public supply; water is carried from St. Winifred's Well; rateable value, 7013*l.*

The town of Greenside also has no public supply. It is built on the alluvium of the *DEE*, at the foot of a terrace of Glacial Drift, over which run several brooks, from which water is carried.

Bagillt.—No public supply. Water is carried from streams flowing off the Glacial Drifts. Scarlet fever is now epidemic (July 1881). Rainfall in 1879, at 20 feet above the sea, 30·97 inches; in 1880, 33·50 inches.

Flint.—*Acres*, 3335; population, 5126; constant supply of 100,000 to 120,000 gallons from reservoir storing a spring and brook; rateable value, 18,268*l.*; 39 & 40 Vict. c. 92.

Connahs Quay.—Supply from small reservoir, impounding brook on cultivated land.

Left Bank of the *DEE*, and tributaries:—

River Alyn.

The *Alyn* falls into the *DEE* between Eaton Hall and Holt; it is 28 miles in length, rising at Llandegla, close to the *CLWYD* watershed, south-east of Ruthin, and near the foot of Cyrn-y-Brain. It follows the strike of the Carboniferous Limestone at the foot of the Moel Fammau range, west of Treiddyn, Nerquis, and Cilcen, whence it turns eastward and crosses the Chert and Siliceous Grits intervening between the Limestone and the Coal Measures, and traverses the Mold Coalfield, and again passes on to lower beds north of Hope, for a short distance, until a fault brings in the Denbigh Coalfield, overlaid by Permians at Gresford, near which the stream turns abruptly to the north-east.

Mold.—*Acres*, 651; population, 4320; constant supply from two reservoirs fed by springs and well in gravel; rate-

able value, 12,417*l.*; the Mold Gas and Water Act, Company spent 700*l.* in 1878. Rainfall in 1879 at Bryn Alyn, 483 feet above Ordnance Datum, 36·94 inches; in 1880, 40·50 inches.

River Clywedog.

This stream falls into the *DEE* above Issacoed. It is 10 miles in length, rising near Minera, one feeder rising between that place and Llandegla, on the eastern slope of the Silurians of Cyrn-y-Brain; other feeders rise on the Carboniferous Limestone, and all flow east over the Denbigh Coalfield, uniting at Wrexham, from which town the river flows over the Permian and Trias.

Wrexham.—Population 10,928; supply from *Wrexham Waterworks Company;* rateable value 40,256*l.*

Following the *DEE* up stream, it leaves the Bunter Sandstones at Ebristock, on which it entered at Queen's Ferry, thence it flows across the Permians fringing the Coalfield, and crosses in succession the Coal Measures, the Lower Carboniferous Sandstone (probably of Yoredale age), and the Carboniferous Limestone, breaching the escarpment of the latter in the well-known Vale of Llangollen. The latter town is situated on the Wenlock Shale, which the river flows over from Corwen, where it changes its direction from a little south of east to north-east, and passes on to Lower Silurians, flowing at the foot of the synclinal ridge of Upper Silurians, culminating in Caerau Crwyni, consisting of Denbighshire Grits, lying on Tarannon Shale. Between this mountain and Corwen, the ridge is breached by the *Alwen*, 11 miles long, rising near the *CONWAY* watershed at Cerrig-y-Druidion. A little west of Corwen it receives on its north bank the *Afon Brenig*, rising near the source of the (*CLWYD*) *Aled*, commencing, like that stream, in small lakes under the watershed. The *Brenig* drains the Denbighshire Grit country around Mwdwl Eithin; the *Alwen* the Bala Beds between Carn Bris and Cader Dinmaen, near Llangwm.

The *DEE* breaches the Denbighshire Grit, lying in a

synclinal between Llandrillo and Llandderfel, passing on to Bala Beds, which continue to the watershed, where they are much intercalated with contemporaneous volcanic lavas and ashes, extensive masses of Felstones forming the Arenigs, Moel Llyfnnant, and Penmaen.

The north-western corner of the basin is drained by the *Tryweryn*, 10 miles long, falling into the main stream at Bala, immediately below the lake; it rises within 15 miles of the sea-coast at Tremadoc; the road from that town to Bala crossing the watershed near its source, and following the bottom of its valley.

Bala Lake extends for nearly 4 miles from Bala to Llanuwchllyn, where its feeder, called the *Afon Llin*, falls in on the north bank. The Great Western Railway, which follows up the *DEE* valley from Llangollen, is carried along the southern margin of the lake, between it and the road, crossing the watershed into the Dolgelly valley, a few miles to the west.

Llangollen.—*Acres*, 3124; population, 3000; constant supply from reservoir impounding brook, supplemented by wells; rateable value, 9393*l.*; Local Government Act, 1858.

Corwen.—Rainfall in 1879, at the Rhug Garden, 500 feet above the sea, 32·58 inches; in 1880, 44·13 inches.

Bala.—*Acres*, 115; population, 1653; scheme for supply will shortly be carried out; at present there are only pumps; rateable value, 2687*l.* 6*s.* 5*d.* Rainfall in 1879, at Henblas, 544 feet above the sea, 43·09 inches; in 1880, 54·99 inches.

Right Bank of the *DEE*.

The southern watershed of the Upper *DEE* runs roughly parallel to Bala Lake and the river from Bwlch-y-Groes to the Berwyn Hills, overlooking the *SEVERN* basin.

The ashy beds of Snowdon, which Professor Ramsay considers the equivalent of the Bala Limestone, are above 1000 feet thick, ranging east to Dolwyddelan and Cerrig-y-Druidion to Bala; but east of this, on the flanks of the Berwyn Hills, they have thinned out, and a few miles south

of Bala Lake the volcanic rocks of the Snowdon Bala outburst have entirely disappeared.

The Bala Limestone at Bala is about 20 to 30 feet thick, is in part compact, fossiliferous, and of a grey colour. Higher up in the Bala series is another band of limestone, which is also fossiliferous, but of a dark blue colour with an oolitic structure, called the Hirnant Limestone. These Lower Silurian rocks dip under the Upper Silurian synclinal, and reappear on its eastern side, and form the Berwyn Mountains.

Mr. Rawlinson states that, whilst examining the Bala district in 1846, a storm swept the Berwyn Mountains. The rain commencing in the evening brought down thousands of tons of stones and gravel, left the old watercourses and swept out new ones, and piled the *débris* over the village of Corwen up to the eaves of the houses and church, remaining so to this day; carrying away bridges which had stood beyond the memory of the oldest man. He considers the dry-weather flow of streams (Chalk and Oolitic surfaces excluded) is to the wet-weather flow as 1 to 300 in ordinary periods, and 1 to 500 and 600 in excessive; and possibly, as Mr. Bateman states, as 1 to 1000 in limited areas, and for very short periods.

Mr. Rawlinson in 1846 proposed to raise the level of the Bala Lake 6 feet, and supply Liverpool and other Lancashire towns, providing works for 60,000,000 gallons a day, and taking half that quantity. He states the average rainfall to be 60 inches. He gauged the weir to supply the Ellesmere Canal at Llantysilio, constructed by Mr. Telford, 3 miles above Llangollen, and found the conduit, which crosses the water across the Pont-y-Cyssyllte aqueduct, taking 20,000,000 gallons a day for the supply of the canal. At Llangollen Bridge, after this abstraction, the average run of 365 days is 55,000,000 gallons.

Mr. Rawlinson's conduit was to start at Llantysilio, 64 miles from Liverpool, draining 289 square miles, with a fall of 10 inches per mile, but this in 1867 he considered far too much, as it would tear the conduit to pieces. The River *Lea*, modified by weirs and stop-gates, has only

6 inches fall; and the Bridgwater Canal, with a velocity of $1\frac{1}{4}$ mile per hour, has only the surface fall given it by drawing the locks at Runcorn; it was laid out by Bentley, and contours the country. With the comparatively small quantities of 2,000,000 to 6,000,000 gallons a day, Mr. Rawlinson considers a grade of 5 feet per mile without danger. He suggests the term "volume" should only be used for water in bulk, and "flow" for water in motion.

No tributary of importance falls into the *DEE*, on its south bank from Bala Lake, until the River *Ceiriog* is reached, rising east of Llandrillo, and flowing by Glyn Ceiriog to Chirk, and then north-eastwards to the *DEE* above Ebristock, flowing successively over Bala beds, Wenlock Shale, Carboniferous Limestone, and Coal Measures, and falling into the main stream at the base of the Permians; flowing in all 15 miles.

The right or east bank of the *DEE*, from Overton to the sea, consists entirely of Triassic rocks, more or less overlaid by Glacial Drift, with one exception, the small tract of Coal Measures faulted in at Parkgate, worked at the Denna Colliery. Between Ellesmere and Chester, the western side of this area consists of Bunter Sandstone, the eastern of Keuper Marls; a narrow outcrop of Lower Keuper Sandstone intervening, faulted by two systems, one ranging about 30° east of north, the other 10° north of west. The base of the Marls is sandy, and interstratified with fine-grained evenly-bedded sandstone, or "Waterstones," resting on the current-bedded compact Lower Keuper Sandstone, which is more or less conglomerate, especially at the base. Between Bangor and Malpas the base of the Keuper Marls is only about 3 miles east of the river, but northwards the Keuper Sandstone escarpment trends north-north-east, and carries the Marls to the back of the Peckforton, Beeston Castle, and Delamere Hills, 10 miles east of the river. At Stanner Nab, on Peckforton, the *DEE* watershed leaves the escarpment, and crosses the Triassic plain by Waverton and Christleton, to the east and north of Chester.

Whitchurch and Dodington (Salop).—*Acres*, 502; population, 3756; no public supply; pumps and wells; rateable value, 13,500*l.* Brine springs were formerly worked at Dirtwich, near the base of the Keuper Marls between Malpas and Whitchurch. Borings 90 feet in depth, at Whitchurch, have only proved Red Sand. Rainfall in 1879, 34·25 inches; in 1880, 41·27 inches.

Chester.—Population, 36,788. The city is built on a terrace or plain of Boulder Clay and Middle Sand, resting on the Pebble Beds of the Bunter, through which the *DEE* has cut a deep valley bridged by the Holyhead Railway. An alluvial plain lies at the bottom, across which the river meanders in swinging curves, well known to boating men. The Local Authority includes 3539 *acres*, with 35,490 inhabitants. The water supply is intermittent, 1,400,000 gallons being taken from the River *DEE*, immediately above Chester, run through a subsiding reservoir and filtered. Rateable value, 136,673*l.* 10*s.* Acts 7 Geo. IV. c. 110; 20 & 21 Vict., 1857; 37 & 38 Vict., 1874.

Rainfall in 1879 and 1880.

	Feet above the sea.	Inches. 1879.	Inches. 1880.
At Newton	62. O. D.	31·81	34·40
„ Lead Works	64	30·04	32·64
„ Curzon Park	74. O. D.	27·14	..
Top of Shot Tower	227	17·60	21·90

Hoole.—*Acres*, 320; population, 2275; constant supply of 17,200 gallons, or 30 gallons per head, from *Chester Waterworks Company.*

Estuary of the DEE—Right Bank.—The Triassic rocks of western Wirral only appear at Burton and Hilbre Points, Boulder Clays, with a Middle Sand, forming cliffs from Denna and Parkgate to West Kirby, which are only breached by small streams.

NESTON and PARKGATE.—*Acres*, 3000; population, 3289; constant supply of 17,000 gallons from reservoir at artesian well in the Pebble Beds, at Little Neston, a mile distant; rateable value, 13,544*l.* 15*s.*; Waterworks Clauses Act, 1863. Rainfall in 1879, at Hinderton, 215 feet above Ordnance Datum, 33·53 inches; in 1880, 31·93 inches.

WEST KIRBY.—An artesian well and reservoir is now being constructed. The surface of the well at Grange Hill is 219 feet above the mean sea-level, the water-level being 32 feet above it, nearer the sea, a mile distant, at the foot of the hill. Mr. I. Roberts, F.G.S., found the water-level to be 22 feet above datum, giving a gradient of 10 feet per mile in a district where no extensive pumping has as yet gone on. The rock penetrated is the base of the Keuper and the Upper Mottled Sandstone.

The watershed of the *DEE* estuary crosses the deep col-valley lying between Thurstaston and Caldy Hills, and ranging through the village of Grange, passes to the sea at Hilbre Point, immediately west of Hoylake. The latter village, Hoose, Great Meols, and Leasowe Castle are built on the Sand Dunes, resting on the peat-plain, drained by the *Birket*, flowing into *Wallasey Pool*, and the *MERSEY*. At Leasowe Lighthouse, submarine peat-beds occur on the shore; a mark on this lighthouse records an extraordinary equinoctial spring-tide, which rose 25 feet above the Old Dock Sill at Liverpool, or 7 feet above ordinary springs.

CHAPTER XXIX.

THE MERSEY BASIN.

O.S. LXXI. (in part).

West Cheshire Streams draining into the MERSEY.—Area, 155¾ square miles,* of which 10 consist of Keuper Marls, and 145¾ of Keuper and Bunter Sandstone.

Wallasey Pool.

The peninsula of Wirral is the promontory of Cheshire; it is surrounded on three sides by the *DEE* estuary, the sea, and the *MERSEY* estuary, and is traversed by a series of north-north-westerly faults which, corresponding in direction with the strike of the Triassic rocks forming the district, cause a repetition of successive lines of escarpment, the most picturesque being those formed by the hard and compact beds forming the base of the Lower Keuper Sandstone, resting on the soft Upper Mottled Sandstones. The valleys between these ridges are filled up to a considerable extent by Glacial Drift, which forms cliffs, ranging from 20 to 100 feet in height, on the *DEE* and *MERSEY* coasts. To the north the country is very low and peat-covered, and is drained by *Birket* Brook, flowing into *Wallasey Pool*, which occupies a gorge, breaking the continuity of the Bidston Hill and Wallasey escarpment. The latter district would even now become an island were the Blown Sand, Peat, and alluvium of the Leasowe plain removed. The central valley of Wirral, from Barnston and Brimstage, is drained by *Fender* Brook, flowing into the *Birket*. Formerly the latter must have

* 'Riv. Poll. Report.' vol. i., 1870.

received an important feeder from high grounds to the north, now destroyed and under the sea, which was instrumental in cutting the transverse gorge of *Wallasey Pool*, which is older than the Glacial epoch, Glacial deposits occurring beneath the bed of the Pool, which has been embanked, and forms the line of docks known as the Great Float, at Birkenhead.

Wallasey.—Population, 21,501; two artesian wells in New Red Sandstone, yielding 800,000 gallons (constant); rateable value, 108,422*l*. The well is 20 feet above the sea-level; the shaft is 90 feet deep, with a 12 and 8 inch boring to 246 feet from the surface; the pumping-level is 30 feet below Ordnance Datum; the rest-level is 4 feet above it.

Birkenhead.—Population, 83,324; supply from wells, headings, and borings in the New Red Sandstone, stored in reservoir, lifted by six pumping engines, supplying 1,810,000 gallons daily; deducting trade supply, 27 gallons are used per head; the rateable value, including Claughton, is 247,319*l*.; additional works are required. Rainfall in 1879, at Bidston Observatory, 182 feet above high-water mark, 29·79 inches; in 1880, 31·34 inches.

Tranmere.—Population, 16,143 in 1871; well with bore-hole, yielding 530,000 gallons daily, stored in a reservoir; rateable value, 80,649*l*.

Analyses made by Dr. Campbell Brown, 11th September, 1878.

Well.	Total solid impurity in solution.	Organic carbon.	Organic nitrogen.	Total combined nitrogen.	Chlorine.	Hardness.		
						Temp.	Perm.	Total.
Spring Hill deep well, rest-level + 11 ft. O.D.	23·0	·093	·002	·389	2·771	6·52	8·06	14·58
Flaybrick Hill, 83 ft., rest-level + 11 ft. O.D.	18·0	·116	·015	·274	4·0	2 12	7·02	9·14
Tranmere, rest-level + 11 ft. O.D. ..	23·0	·131	·004	·273	2·82	3·44	11·14	14·58

All these waters are free from sewage contamination, but are harder than when analyzed in 1874. The three Birken-

head wells, the Prenton well, and the Wallasey well, are all situated on the same belt of rock, lying between the *Fender* Brook and Tranmere Faults. The Wallasey, Flaybrick, and Spring Hill wells penetrate the Lower Keuper Sandstone and the Upper Mottled Sandstone, the Tranmere and Prenton wells the latter formation only. It appears to be somewhat doubtful that the Pebble Beds were reached, though possibly they were touched by the deep bore at Flaybrick and at the bottom of Prenton.

Part of the district south of Birkenhead is supplied by the *Wirral Waterworks Company*. Their well is at Prenton. It was sunk under the direction of the late Mr. J. Cunningham, C.E., and passed through 18 feet of Boulder Clay and 352 feet of soft Sandstone; 400,000 gallons are pumped daily, but it could yield more than 2,000,000; the rest-level is 79 feet above Ordnance Datum; the pumping-level 14 feet above it.

Bromborough Pool.

This stream drains a valley cut in the Glacial Drift, resting on the Upper Mottled Sandstone, from Hooton to Bebington and Bromborough, where the soft deep-red basement beds are well seen.

River Gowy.

Pebble Beds, Upper Mottled Sandstones, and impermeable Red Marls occupy about 22 square miles in the basin of the *Gowy*, and small streams east of it, flowing into the estuary of the *MERSEY* near Frodsham. These streams rise on the Red Marl plain, or in the Keuper Waterstones, and flow down the Triassic escarpment, between Burwardsley and Frodsham.

Tarporley.—*Acres*, 5915; population, 2669; supplied by wells and springs in the Keuper Sandstone, yielding about 10,000 gallons a day; rateable value, 13,402*l*.

Hargrave, Christleton, Dunham, and Thorbiton, all of which could get good supplies of water from the Bunter Pebble Beds.

RIVER WEAVER (*LXXI., in part*).

Length, 53 miles. This basin is bounded to the west by the watershed of the *DEE*, to the south by that of the *SEVERN*, east by the *TRENT*, and north by the *MERSEY*. The area of the united streams of this basin, including brooks draining directly into the *MERSEY* estuary, is 696 square miles.

The area of the *WEAVER* alone, with its tributaries, is 540¼ square miles, of which 45 consist of Coal Measures, 3 of Permian, and 474¼ of Triassic rocks, of which 7 are New Red Sandstone, leaving no less than 467¼ square miles occupied by Keuper Marls, while a further 10 miles are occupied by the Liassic outlier east of Whitchurch. Following the left bank of the *WEAVER* from its mouth at Frodsham, it passes at once from the Keuper Waterstones on to the Keuper Marls, which are thickly covered with deposits of Boulder Clay, Sand, and Gravels; water absorbed by the latter, at an average elevation of 300 feet, percolating through a porous band, above the upper Salt-rock, is the source of the brine issuing at pressure in natural springs, and met with in the Artesian Shafts at the various brine pumping-stations. Pumping has reduced the level to which brine will rise, and most of the springs between Frodsham and Castle Northwich have ceased to flow. Near Whitegate and Marton, brine outbursts have recently taken place at more than 80 feet above the sea.

The *WEAVER* rises near the base of the Keuper Marls, at the top of the Triassic escarpment overhanging the valley of the *DEE*, near Rowton Heath; thence over the plain of Keuper Marl south-eastwards to the Lias east of Whitchurch. Reaching the margin of this outlier, it turns abruptly northwards, and flows past Nantwich, at 120 feet above the sea, and Northwich at 30 feet above the sea, where it receives the *Dane* and turns westwards, falling into the estuary of the *MERSEY* below Runcorn. The Ellesmere Canal, connecting the *SEVERN* and *WEAVER* basins,

crosses the extreme south-eastern corner of the *DEE* basin, the level of the watershed between the *DEE* and the *WEAVER* being 310 feet, and the same elevation between the *DEE* and the *SEVERN*. The canal crosses the head waters of the *WEAVER* at 251 feet, and joins the canal connecting Chester with Wolverhampton at 212 feet above the mean sea-level. The latter canal crosses the *WEAVER* and *SEVERN* watershed at 312 feet, near Market Drayton. An important feeder of the *WEAVER* rises near this point, falling into the main stream near Audlem.

Nantwich. — *Acres*, 696; population, 7488; partially supplied by gravitation from Baddiley Mere, at a distance of 4½ miles from the town; gathering-ground of 600 acres. There are two reservoirs, capable of holding 14,000,000 gallons; water filtered through stone and coarse sand, in all 6 feet thick; supply constant, except in drought; rateable value, 1420*l.*; Public Health Acts. Rainfall in 1879, Cholmondeley Castle, 35·43 inches; in 1880, 41·02 inches.

In the district lying south of this town Brine Springs still rise to the surface at several points on the banks of the *WEAVER*. The most southern is that at Audlem, where a boring, carried through the Lias, and into the Keuper Marls, met with the brine at 300 feet, which rose to the surface 175 feet above Ordnance Datum. Other springs flow daily into the *WEAVER*, at Brine Springs Farm, at Austerson's Farm, at Shrew Bridge, at 112 feet above Ordnance Datum. Formerly it flowed to the surface at Welshman's Bridge, close to the old Brine Shafts, which are now no longer worked, though at one time this was a considerable centre of the salt trade, in the limited proportions that it formerly assumed. Brine outbursts took place in 1539 at Combermere Abbey, accompanied with subsidence, and the formation of a mere, and another subsidence took place 1659 at Barmere. Borings into the Lias between Whitchurch and Market Drayton prove the Glacial Drift to be there more than 50 feet thick. Between the latter place and Crewe, numerous feeders chiefly drain a Boulder Clay district.

CREWE.—Population, 24,372; intermittent supply from wells 11 miles south, at Whitmore, near Madeley, Staffordshire, belonging to the London and North-Western Railway, who sell the water to the Town Council by meter. The water from this well is remarkably soft, containing, according to Dr. Zeidler, only 6·10 grains of solid matter per gallon. The Lower Mottled Sandstone here is absent, and the well is sunk in the Pebble Beds; whether it reaches the underlying Permian Sandstones is doubtful. Rateable value, 63,019*l.* 18*s.* 7*d.*; main laid under Public Health Act, 1875.

Alsager.—A boring has been carried to a depth of nearly 1000 feet, at a point 300 yards from the Station (North Stafford Railway) and 310 feet above the sea. The water was reached in the borehole at 553 feet, and therefore 243 feet below the sea, and the water rises 12 feet above the surface. Marls, with bands of grey rock, with thin bed of gypsum, occupied the first 553 feet, the water occurring at the top of the Sandstone; this was bored into to a depth of more than 400 feet without increasing the supply. The outcrop of the Keuper Waterstones is about three-quarters of a mile south of this borehole, and the dip of the beds is at 25 degrees to the north-north-west, which would take the base of the Marls down to the depth they were found in the borehole. The water obtained was of good quality, and was doubtless absorbed in the area of Lower Keuper Sandstone, about a square mile in extent, lying west of the north-east fault, cutting off the Keuper Marl tract, and throwing up the Bunter Sandstones and the North Staffordshire Coalfield. Half a mile north of the boring there is a lake, 11 acres in extent, called Alsager Mere, without inlet or outlet, the water of which is very clear, and believed to be pure. The lake is said to ebb and flow, and to sometimes rise in level even in dry weather.

Following the right bank of the *WEAVER* from Nantwich, the valley is cut through Middle Glacial Sands at Minshull Vernon, Winsford, and Clive, and they underlie the Upper Boulder Clay at Wharton and Moulton.

Winsford.—*Acres*, 5647; population, 10,041; Stretches Springs at Little Budworth, collected in reservoir (with water tower), could supply 239,750 gallons, but only 45,500 gallons are taken, only 5000 of the population being supplied; rateable value, 50,516*l.*; Public Health Act, 1875.

River Dane.

This tributary is 32 miles long, rising between Congleton and Leak, near the head waters of the *Churnet* and *Wye*, tributaries to the *TRENT*, and those of the *MERSEY*, which is formed by the junction of the *Goyt* and *Etherow* at Water Meetings. The *Dane* rises on the western flank of Axe Edge, and runs at first with south-westerly course along the hollow of the Goyt Trough; then, turning to the west, it cuts through the Grit ridge of Back Forest, and flows past Congleton and Middlewich into the *WEAVER* at Northwich. The southern feeder of the *Dane* rises on Yoredale rocks, thence it flows over the Pebble Bed outlier near Leak. Another feeder gives a very good section of the Lower Coal Measures of the North Staffordshire Coalfield, occupying a synclinal fold in the Millstone Grits between Wetstone Hale and Goldsitch House, thence it cuts a gorge through the third Millstone Grit in Back Forest. At Hug Bridge it passes across an outlier of Pebble Beds, resting on Permian Sandstone, lying on the Yoredale rocks, which it then traverses up to the Red Rock fault throwing in the Red Marls. These have been bored into at Howford Bridge, Buglawton, near Congleton, to a depth of 165 feet, of which 137 feet consisted of alternations of Marls with thin seams of blue, hard, fine-grained Sandstones, the remaining 28 feet being hard grey rock.

Congleton.—*Acres*, 2584; population, 11,116; wells in drift sand and gravel, belonging to the Glacial Drift, which deeply overlies this country, supported generally by the Lower Boulder Clay; rateable value, 30,687*l.*

Buglawton.—*Acres*, 2852; population, 1550; wells and spring; rateable value, 10,209*l.* Rainfall at the Vicarage

in 1879, 347 feet above the sea, 34·41 inches; in 1880, 37·28 inches.

Middlewich.—*Acres*, 237; population, 3379; springs and wells; rateable value, 6201*l.* Brine Springs have been worked here for centuries. The tops of the shafts are about 100 feet above Ordnance Datum, and the brine rises to about 15 feet from the surface; the level is higher on a Monday than on a Saturday. Borings have been carried down from the bottom of the shafts, but no rock-salt was met with. Rainfall at Bostock Hall, 157 feet above Ordnance Datum, in 1879, was 32·46 inches; in 1880, 35·11 inches.

River Wheelock.

The *Dane* receives this tributary at Middlewich. It is 7 miles in length; it rises on the Red Marls, thence flows to the Red Rock fault, between Congleton and Talk, as does its southern feeder *Creswellshaw* Brook, which falls into the *Wheelock* at the village of that name. At the same point also falls in another brook, rising near the fault, and flowing through Betchton. The Grand Trunk Canal follows the lines of these valleys, crossing into the *TRENT* basin above Stoke, at 363 feet above the mean sea-level. At Wheelock, Malkin Bank, and Lawton, in the *Wheelock* valley, are brine pumping stations; at the latter place rock-salt was discovered at the end of the last century. The rock is not now mined, but brine is pumped from it.

Sandbach.—*Acres*, 2584; population, 5493; supply from wells in Glacial Drift; rateable value, 19,104*l.* 3*s.* 5*d.*

The sands of the Middle Drift are well seen at Sandbach station, and northward to the valley of the *Dane* the whole country is deeply covered with Drift. From the latter valley to the watershed at Macclesfield the country rises steadily to 500 feet above the sea, the base of the Keuper Marls there attaining that elevation. Westward *Peover*, *Twam*, and *Wincham* Brooks drain chiefly an Upper Boulder Clay country, and fall into the *WEAVER* at Northwich.

NORTHWICH.—*Acres*, 1758; population, 12,246; supply constant, 30,581 gallons from a well 36 feet deep, and water abstracted from *Wade* Brook, a mile distant from township boundary, filtered through gravel, sand, and charcoal into a reservoir, thence pumped into high-service uncovered reservoir holding 44,000 gallons. The Rivers Pollution Commission does not consider it a good water. The total solid impurity was 27·96; chlorine, 2·43; total hardness, 14·0, of which 11·6 was permanent; rateable value, Local Board, 31,000*l*. The Rivers Pollution Commission states the water of Rostherne Mere, near Knutsford, had a total solid impurity of 20·34, hardness of 15·4, of which 10·6 was permanent. Rainfall at Highfield in 1879, 118 feet above Ordnance Datum, 32·28 inches; in 1880, 35·34 inches.

Brine springs and two beds of rock-salt occur at Northwich. The following is the section of the oldest mine in the district:—

Marston Mine.

	Feet.	
1. *Drift:* Boulder Clay		144
2. Red Marl		
3. *First Salt Rock*	75–84	
4. Indurated Clay	30	126
5. *Second*, or *great salt rock* bed	96	

The upper salt bed, Mr. Ormerod states, is 90 feet thick north-west of Northwich, decreasing eastward to 81 feet, and thinning also south-westward at the rate of 15 feet per mile. The upper portion of the lower bed is not worth working, but the lower 15 feet is mined; the entire thickness of this seam in one instance is more than 117 feet. The upper bed was discovered in 1680 at Marbury, in sinking in search of coal; the lower and more valuable bed was not discovered until the end of the last century.

The Rivers Pollution Commission states* that the basin of the *WEAVER* contained, in 1801, 71,919 inhabitants; in 1871, 135,787.

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* Vol. i. 'Report.'

RIVER MERSEY (*CI.*).

The *MERSEY*.—Length, 56 miles; area, 912, of which the Keuper Marls occupy 105 square miles, the New Red Sandstone 227, Permian 24½, and Coal Measures and Millstone Grit 566, of which 181 lie on the south bank of the *MERSEY* and the *Etherow*, and in the basin of the *Goyt* and *Bollin*.

The estuary of the *MERSEY* occupies a broad and extensive area between Runcorn and Garston, contracted at the entrance between Liverpool and Seacombe. In the Ordnance Survey Catchment Basin Map the estuary of the *MERSEY* lying north of the *DEE* watershed is relegated to the *WEAVER*, and the Lancashire shore, west of Garston, is amalgamated with the *ALT* Basin.

Runcorn.—*Acres*, 820; population, 15,133; rateable value, 44,638*l.*; constant supply from well in New Red Sandstone, pumped into high-level reservoir. The Runcorn, Weston, and Halton Waterworks Act, 1865.

The watershed between the *WEAVER* and the *MERSEY* commences at Runcorn Point, and trends south-east by High Leigh, Knutsford, to near Bosley, 5 miles south of Macclesfield, thence it turns north-east to Forest Chapel, and again south-eastwards for a short distance around the sources of the *Goyt*, and eastward terminating against the central watershed of England, which here separates the *TRENT* Basin from the *Dane* and the *MERSEY* Basin, trending west of Buxton, east of Chapel-le-Frith, following the high ground of the Peak, it passes east of Glossop and falls into the minor watershed separating the waters of the *TRENT* from those of the *DON*, at a height of 1700 feet above the sea, trending north-west.

At Todmorden, the direction changes where the *MERSEY* watershed leaves the Pennine chain at a point 1200 feet above the sea, and trends south-west to Garston in the *MERSEY* estuary, passing south of Burnley at 1248 feet, south of Accrington at 1238 feet, south of Over Darwen at 1295 feet, above Horwich at 1183. Descending the hill, and crossing Red

Moss, near Blackrod, it ascends the ridge on which the village is built, once traversed by a Roman road, thence it bounds the basin of the *Douglas*, passes south of Wigan, where the watershed is crossed at 110 feet above Ordnance Datum, trending thence north-west it rises to 436 feet at Upholland, thence near Bickerstaffe, where it has descended to 201 feet above Ordnance Datum, and trends southwards, passing west of *Rainford* Brook and St. Helen's to Garston.

From opposite Warrington to the infall of the *Bollin*, the strike of the strata runs parallel to the river; they consist of Upper Mottled Sandstone at the bottom of the hill at Latchford, Thelwall, and Statham, dipping under an escarpment of Lower Keuper Sandstone, by Appleton, Grappenhall, and Lymm. The upper beds are the true Waterstones, and contain Labyrinthodont footprints.

Lymm.—*Acres*, 4375; population, about 4665; this district and Oughton supplied by a Company; rateable value, 25,000*l.*; works under 37 & 38 Vict. c. 29, 1874; Lymm Water Act. Rainfall at Statham Lodge, 42 feet above the sea, was 30·17 in 1879; in 1880, 32·31 inches.

The south bank of the *MERSEY* above the infall of the *WEAVER*, exclusive of the *Bollin*, receives, according to the Rivers Pollution Commission, the drainage of 107 square miles.

The country south of Lymm consists of Red Marls, and is drained by *Bradley* Brook, while good sections of the Waterstones are observable on the banks of the reservoir and lower down in the village; the basement beds are seen resting on the Upper Mottled Sandstone; where the stream falls into the *MERSEY* at Lymm Ees, it is called *Sow* Brook.

River Bollin.

At Heathley Hentin the River *Bollin* meets the alluvium of the main stream, into which it falls below Warburton. This tributary is 14 miles long, and drains 111¾ square miles, of which Carboniferous Rocks occupy 13¾, Triassic Sandstone 17, and Keuper Marls 81 square miles. Following its

left bank from its infall it receives *Agden* Brook, draining the Waterstones around Millington and the Red Marls of High Leigh, with this exception, the *Bollin*, for the first 9 miles of its course, and all its tributaries on both banks, drains a Keuper Marl country covered more or less with Boulder Clay and Middle Sand. South of Bowdon, it receives the River *Birkin*, draining Rosthern and Tatton Park Meres and Ollerton, and, with *Ashley* Brook, the country round Mobberley, Great Warford, and Alderley.

Beds of Keuper Marls with Gypsum rolling in various direction are seen in the *Bollin* from the infall of the *Birkin* to Quarry Bank Farm, between Ringway and Wilmslow, where the base of the Marls is seen resting on the Waterstones; thence, tracing it on towards its source, it flows by Wilmslow, Mottram Andrew, and Prestbury to Macclesfield, a distance of 10 miles, over Triassic Sandstones, following to a great extent the strike of the Upper Mottled Sandstone. East of Macclesfield it crosses the fault bringing up the Carboniferous rocks, and its feeders rise in the Yoredale rocks and Millstone Grits of Macclesfield Forest, between Forest Chapel and Wincle.

Following the right bank of the *Bollin* from its source, no tributary of importance comes in, until the River *Dean* joins it at Wilmslow. This stream flows south of Handforth over Keuper Marls, entering the New Red Sandstone south-east of the Railway Station, and passes south of Woodford and under the Manchester and Macclesfield Railway at Owlers Lane, 334 feet above the sea, following the strike of the Pebble Beds, and flowing nearly parallel to the course of the *Bollin;* crossing the Red Rock fault, it enters the Lower Coal Measures west of Bollington, and drains a Millstone Grit country between Rainow and Jenkin Chapel. The sandstones of this series are permeable, intercalated with impermeable shales dipping towards the Red Rock fault, so that all the water issuing at springs in this area is returned to the basin in which it is received.

Below the infall of the *Dean* and north of the *Bollin* lie the

villages of Styal, Ringway, and Bowdon, *acres*, 828; population, 2262; rateable value, 25,247*l.*; supply from the *North Cheshire Water Company*, who obtain water from the mains of the Manchester Corporation.

Sinderland Brook.

North of Warburton good sections of the base of the Keuper Marls and of the Waterstones are exposed in the banks of the *MERSEY* at Hollingfare, opposite which place the river receives *Sinderland* Brook, which follows the boundary between the Marls and Waterstones to near Timperley Station, where it divides; the southern feeder being *Timperley* Brook, rising on the Red Marls north of Ringway and flowing past Altrincham, the northern being *Bagnelly* Brook, rising on the Red Marls at Northenden Etchells and flowing over them to the north of Timperley.

Altrincham (Cheshire).—*Acres*, 657; population, 11,249; from *North Cheshire Water Company*, who obtain their supply from Manchester Corporation; rateable value, 51,489*l.*; North Cheshire Water Acts, 1864 and 1877.

The infall of the *Irwell* comes in at Carrington, at 40 feet above Ordnance Datum. The *MERSEY* from this point up to Stockport is often called the *Stockwell;* 4 miles east of the latter town it divides into the *Etherow* and the *Goyt.*

From Carrington to Ashton-on-Mersey the southern valley of the *MERSEY* consists of Upper Mottled Sandstone. At the latter place a north-north-west fault with an easterly downthrow throws the base of the Red Marls 3½ miles to the north, and the river flows over Keuper Sandstones to the bend in the stream east of Northenden, opposite Didsbury, where the Bunter Sandstone comes in.

A tributary rising on the Coal Measures of Lyme and Poynton Park, and flowing over the Pebble Beds of Bramhall and Adswood and the Upper Mottled Sandstone of Cheadle, falls into the main stream below the bridge.

Between Cheadle Bridge and Stockport the river flows over Pebble Beds resting on the Permian Sandstones, twice

brought to the surface by north-north-west faults. The Permian is again traversed for the third time at Stockport, and continues to the Red Rock fault, bringing in the Cheshire Coalfield near Offerton Green; the Lower Mottled Sandstones are absent all along the boundary of the Coalfield, the Pebble Beds resting on the Permian, and within is the coal area directly on the Carboniferous rocks. The bottom of the valley at Stockport is 140 feet above the mean sea-level, the top of the terrace is 256 feet (at St. Thomas' Church), the Permians at Hazel Grove, 295 feet.

STOCKPORT.—Population, 59,544; rateable value, 180,293*l.* 15*s.* 1*d.*; it is supplied by the *Stockport District Waterworks Company*, who obtain their supply from Lyme and Woodhead. The full supply is about 1,500,000 gallons per day to 60,000 persons, or 25 gallons per head per day for all purposes, partly supplied by the *Manchester Works*, under an agreement to provide any quantity of water required not exceeding 1,000,000 gallons per day, and partly by the *Stockport District Waterworks Company;* store reservoir at Lyme Park, and watershed 6 miles distant. During the 1868 drought, the Manchester supply was reduced in September, and it became apparent the Lyme Park reservoir would fail; recourse was had to wells existing at two old pumping stations in the town, from which the original water-supply was obtained.

The south-eastward trend of the *MERSEY* valley is continued across the Red Rock fault to the base of the Middle Coal Measures, near Offerton Green, whence it trends north-eastward, which direction is continued by the River *Etherow*, one of the two streams into which the *MERSEY* divides at Water Meetings.

River Goyt.

This stream, flowing from the south-east, drains 70¼ square miles, entirely consisting of Yoredale and Millstone Grit area. The Peak Forest Canal is carried along its left bank, falling into the Macclesfield Canal between Hollins and

Marple. The Stockport and Buxton Railway also traverses the left bank of the upper portion of the valley. In 1801 the basin was inhabited by 9287 inhabitants, in 1861 by 17,790.

Marple.—*Acres*, 3210; population, 4421; no public supply; the existing wells are wholly inadequate; rateable value, 20,177*l.*

Following the east or right bank of the stream from its source, a synclinal of Lower Coal Measures, with a north-east axis, is crossed between Whitehough and New Mills; the latter is on the Rough Rock or First Millstone Grit, *acres*, 4834; population, 6600; a reservoir, made by the late Mr. G. W. Newton, now the property of Mr. F. J. Sumner, gives an intermittent supply to one-third of the district; another part of the district receives a constant supply from the reservoir of Mr. T. J. Phillips Jodrel; rateable value, 20,146*l.*

River Etherow.

North of Mellor the *Etherow* comes in from the north-east, draining 59¾ square miles, and, like the *Goyt*, drains a Lower Carboniferous area. Following the left bank from its infall, it flows past the Lower Coal Measures of Ludworth Intake and the Rough Rock of Charlesworth, it receives the stream draining the Yoredale and the Lower Millstone Grits of Glossop Dale, and drains on this bank 32½ square miles. The *Etherow* may be considered as the Upper *MERSEY*.

Glossop is situated on the Kinderscout, or Fourth Millstone Grit. There are 19,574 inhabitants; supply under the Glossop Waterworks Act, 1865; the two reservoirs are the property of Lord Howard of Glossop; negotiations for their purchase by the Local Authority are in progress. Rainfall in 1879, at Spire Hollin, 612 feet above the sea, 39·11 inches; in 1880, 48·45 inches.

In the angle formed by the junction of *Glossop* stream and the *Etherow* is the site of Melandra Castle. Between this and Hadfield, an east and west fault with a southerly downthrow cuts off the Lower Coal Measures and higher Millstone Grits at Mottram, and brings in the Kinderscout and

Yoredale Grits, until they are cut off by the north and south fault emerging east of Stalybridge.

Right Bank of the *MERSEY* and *Etherow.*

The right bank of the *Etherow* drains 25¾ square miles of Carboniferous Rocks. It rises on the western slope of the Pennine chain; its head waters, draining 18,900 statute acres, form the drainage-ground of the *Manchester Corporation Waterworks,* of which the following table gives some details:—

Name.	Area.	Capacity. Million Gallons.	Depth.	Topwater Above O.D.L.	Distance, Higher End in Miles.
	Acres.		Feet.		
Woodhead	135	1235	72	777	18
Torside	160	1474	84	653	16
Rhodes Wood	54	500	63	576	15
Arnfield	59	209	52	541	12
Hollingworth	13	73	52	555	11¾
Godley	15	61	21	478	8¾
Denton	13	53	20	323	5
Gorton	57	223	29	245	4¼
Prestwich	4½	20	22	..	..

These figures are taken from Sir Joseph Heron's statistics of the works, given to the Rivers Commission in 1867. The first three reservoirs impound the *Etherow,* and Sir Joseph stated it was intended to construct below them the Vale House Reservoir, holding 355,000,000 gallons, and the Bottoms Reservoir, holding 399,000,000 gallons, in all giving a capacity of 4,602,000,000 gallons. The Hollingworth and Arnfield reservoirs are on tributaries of the *Etherow,* bearing these names, and are included within the drainage area mentioned above. All beyond the first five in the list are outside it, and the four last outside the watershed of the *Etherow.* The reservoirs are situated between the Manchester, Sheffield, and Lincolnshire Railway and the Manchester and Hyde turnpike road, and run parallel to the road from Tintwistle, being carried through the hill at Mottram in a

tunnel 2 miles in length. North of Broadbottom Station, from Godley the pipe is laid down the road, through Hyde, Denton, Gorton, and Ardwick; a branch conduit, branching off at Hyde, and looping back, crosses the old main at Denton, and traverses Openshaw and Cheetham Hill to Prestwich. The following figures are given by Mr. Bateman as the mean rainfall of the *Manchester Waterworks* district:—

Mean rainfall 50 inches.
Mean „ of 3 dry years 40¼, of which 33 inches can be collected.
Rhodes Wood Min. of 12 years 34·49 Mean 44·20 .. 78 per cent.
Woodhead „ „ 40·33 „ 48·83 .. 84 „

Manchester Reservoirs.

Rainfall in 1879 and 1880, observed by Mr. Bateman.

	Feet above Sea.	Inches. 1879.	Inches. 1880.
At Godley Reservoir	500	31·18	37·09
„ Rhodes Wood „	520	41·91	50·73
„ Arnfield „	575	39·57	46·98
„ Torside „	600	43·14	52·90
„ Woodhead „	680	46·61	56·97

Mr. Taylor, reporting to the Rivers Pollution Commission in 1868, when the population of Manchester was 470,000, states the supply was 15,000,000 gallons per day, or 32 gallons per head, from a gathering-ground on the upper valley of the *Etherow* of 18,900 acres; the yield of the springs is 16 cubic feet per second, or 8,500,000 gallons per day, the balance of 6,500,000 being supplied out of the storage reservoirs. The compensation water to mills in 1868 was 55 cubic feet per second, for 12 hours a day, or 15,000,000 gallons per day, making a total demand of about 30,000,000 gallons per day, to supply which 25½ inches would be required to run off the ground and be stored, out of

an average rainfall of the last 14 years of about 46 inches; or, in other words, the safe limit of a gravitation supply, the *available minimum*, had then been nearly reached. In 1865 the Woodhead reservoir could not be filled within 20 feet of its full height owing to a landslip and the unsoundness of the embankment, and the Torside reservoir from a matter of prudence, it being thought desirable to increase the level year by year by a foot or two, and also because the raising of the level to the full height would have drowned out the Crowden Bleach Works, which have been since purchased and removed by the Corporation. Since 1865, two new compensation reservoirs have been constructed below the Rhodes Wood Reservoir, called the Valehouse and Bottoms Reservoirs, which hold 750,000,000 gallons, or 50 days' supply of compensation water, which has been reduced from 75 to to 55 cubic feet per second for 12 hours per working day, affording an increase of 5,400,000 gallons of water per day for the use of the town. This relief was effected by its purchase from the millowners. Had this not been so the works would have failed to give the requisite supply in 1865.

Following the right bank of the *Etherow*, it flows through Long Den, passes the reservoirs, and crosses the Mottram east and west fault; it drains tracts of Lower Coal Measures, much broken and dislocated, overlying the Rough Rock of Weneth Low; between Compstall and Chadkirk it is joined by the *Goyt*, and becomes the *MERSEY*, which drains the Lower Coal Measures of Romily, Bradbury Green, west of which the Upper Coal Measures come in, until they are cut off by the Red Rock fault, running north-north-west by Midway House and Hyde Hall, throwing in the Permian, which occupies all the country lying between the fault and the Rivers *MERSEY* and *Tame*.

Hollingworth.—*Acres*, 2130; population, 2658; rateable value, 96,009*l.*; one-fourth of the supply from reservoir, rest from springs, wells, and pumps.

Mottram-in-Longdendale.—*Acres*, 1084; population, 2911; rateable value, 10,000*l.*; no public supply; natural

springs and wells; reservoir required to intercept the springs.

The basin of the *Etherow* in 1801 was inhabited by 7307 inhabitants, in 1861 by 30,384.

River Tame.

The *River Tame* falls into the *MERSEY* below Castle Hill, Stockport, from the north-east following it up stream past Brinnington and Reddish Mills for 3 miles, it crosses the fault at Horden Hall, the Permians overlapping the Upper Coal Measures; at a short distance from this point it crosses the whole of the North Cheshire Coalfield at right angles to the strike as far as Hougham Dale, where it turns northward to Hyde, and trends first nearly with the strike, and then obliquely to it, so as to flow over higher and higher beds, until at Guide Bridge it reaches measures above the highest seam of the Middle Coal Measures. It drains 59½ square miles of country, of which 3½ are Permian and the remainder Carboniferous.

Several brooks rise in the Millstone Grits and Gannister Measures of Matley Moor, Godley, and Newton, and flow west into the stream below Guide Bridge, north of which the stream again turns eastward, and for the second time cuts across the entire coalfield. The seams dip west at angles of 20° to 30°, so that the horizontal distance between the outcrop of Great and Roger Mines and the Royley Mine, the representatives of the Ince Mines and Arley Mine of Wigan, is only three-quarters of a mile. The outcrop of the Royley Mine, the base of the Middle Coal Measures, occurs at Dukinfield, near which is the Dukinfield Colliery, 760 yards deep. Eastward to Stalybridge the river traverses the whole of the Lower Coal Measures in the space of a mile, with an average dip of 20°.

East of Stalybridge the river crosses the Rough Rock, and flows a little obliquely to the strike of the underlying Millstone Grits, so that it gradually in ascending towards its source gets on lower beds. On the hill-side above

it, and running about north, or nearly parallel to it, is a fault with a westerly downthrow, which crosses the *Goyt* between Disley and Mellor, and the *Etherow* at Compstall, and cuts off the Mottram fault. East of this fault, and north of the latter, is a tract of wild country, consisting of Yoredale Shale and Kinderscout Grit dipping east, while the Millstone Grits west of it are dipping west, which gives to this fault its name of the "Anticlinal fault," which crosses the *Tame* near Greenfield Station. East of this the stream flows through the Saddleworth valley, which is traversed by an anticlinal running east of, and parallel to the fault, bringing in the Yoredale series, consisting of shale, with a thick bed of Grit in the centre. At Dobcross the stream divides, the western feeder draining chiefly the country west of the anticlinal fault, the eastern feeder the Saddleworth valley. The Manchester and Huddersfield Railway, which runs along the right bank of the stream from Guide Bridge, here crosses on to the left, and north of Diggle Station is carried through the Pennine watershed in the Standige Tunnel, $2\frac{3}{4}$ miles long.

Hyde.—*Acres*, 3956; population, 28,629; constant supply from reservoirs storing springs of 200,000 gallons; rateable value, 99,000*l.*; the waterworks were purchased under 33 & 34 Vict. c. 17.

Dukinfield.—Population, 16,943; constant supply of 214,000 gallons from reservoirs, storing springs from the Millstone Grit hills; rateable value, 59,755*l.* Old works purchased under Ashton and Stalybridge Corporation Waterworks Act, 1864. New works being established under Ashton, Stalybridge and Dukinfield District Waterworks Act, 1870 and 1875. The works were vested in a joint committee on the 1st of July, 1878, under the Acts of 1870 and 1875, have to be worked, and then will be held jointly by those places and Mossley and Hurst.

Stalybridge.—*Acres*, 783; population, 22,784; rateable value, 71,740*l.*; constant supply of 420,000 gallons, from impounding reservoirs at Knott Hill and Swineshaw,

and new works at Greenfield; joint waterworks, under 27 & 28 Vict., 1864, as above.

Rainfall in 1879, at Swineshaw, 884 feet above Ordnance Datum, 40·96 inches; in 1880, 44·31 inches.

The valley of the *Tame*, on the right or west bank of the stream, has a very short slope, the *Medlock* watershed running parallel to and often within a mile of the river. This ridge is tunnelled through by the Oldham and Delph Railroad, west of Lidgate; along the top of the ridge, known as Quick Edge, runs a Roman road, by Mossley. The short western slope continues by Lussley, St. George's, Stalybridge, Ashton-under-Lyne, Denton, Haughton Green, and Reddish.

The Manchester and Ashton Canal enters this valley on the right bank, near Guide Bridge; the Ashton and Huddersfield Canal crosses to the left bank, between Ashton and Stalybridge, recrossing at Greenfield Railway Station, whence the railway is carried beside it, and through the Pennine escarpment at Pule Hill.

Mossley.—Population, 13,372; rateable value, about 36,000*l.*; supply of about 30 gallons per head from Ashton Joint Waterworks; under 33 & 34 Vict., 1870, and Amendment Act, 38 & 39 Vict., 1875, as above.

Hurst.—Population, 6382; constant supply of about 30 gallons per head, from *Ashton Joint Waterworks*.

Ashton-under-Lyne.—Population, 37,027; constant supply from *Ashton Joint Works;* Ashton-under-Lyne Corporation Waterworks Act, 1855, and Ashton Joint Acts.

Audenshaw. — Population, 5930; constant supply from *Ashton Joint Works;* rateable value, 16,000*l.*

The *MERSEY*, from Stockport to Didsbury, flows through a broad valley, mainly excavated in Glacial Drift, from Heaton Norris and Withington to Manchester, consisting of Upper Boulder Clay, Middle Sand and Gravel, and Lower Boulder Clay, which outcrop in the valley, though to a certain extent they are there obscured by terraces of alluvial gravel in the valley, and on the plain above by a thin

covering of a post-Glacial sand. The Didsbury and Withington district is drained by a series of brooks running from east to west over the Drift; the most important of which is *Gore* Brook, rising over the Permians of Audenshaw, west of Guide Bridge, which is impounded at Gorton, flowing over Glacial deposits overlying Pebble Beds, through Rusholme, by Birch Church, and north of Withington, where Upper Mottled Sandstone crops to the surface, and thence north of Chorlton-cum-Hardy, where it enters the alluvium of the *MERSEY*, falling into the main stream, near Stretford.

From Stretford, by Urmston and Flixton to the *Irwell*, the whole country is deeply overlaid by Glacial Drift, more or less covered by post-Glacial Sand on the upland plains, and connected by terraces of alluvium in the bluffs bounding the alluvial plain of the river.

Manchester Corporation Waterworks supply : — Gorton, population, 33,091; rateable value, 100,000*l.* Withington, *acres*, 5729; population, 17,108; rateable value, 104,549*l.* 10*s.* Rusholme, *acres*, 1160; population, 11,237; rateable value, 72,350*l.* Stretford, population, 19,025; rateable value, 108,000*l.*

Rainfall in 1879 and 1880 at—

	Feet above Sea.	Inches. 1879.	Inches. 1880.
Urmston	80	31·51	35·22
Withington	110	31·15	34·65
Plymouth Grove	150 (O.D.)	33·35	36·00
Fairfield	312?	31·23	36·80
Alexandra Park	95	36·48	..

CHAPTER XXX.

THE BASIN OF THE IRWELL, AND RIGHT BANK OF THE MERSEY BELOW IT.

River Irwell.

THIS important river is twenty-eight miles long, drains 311¾ square miles, inhabited in 1801 by 253,327 inhabitants, in 1861, by 1,014,569. Of this area, 273¾ miles consist of Carboniferous rocks, 107 Permian, and 28¾ of Triassic Sandstone. Following its left bank from Flixton, it traverses the Upper Mottled Sandstone concealed by Drift. At Hulme Bridge it receives *Longford* Brook, rising west of Victoria Park, and flowing west through Croft and Davy Hulme. The Bridgwater Canal crosses the river opposite Barton-upon-Irwell, having previously crossed the *MERSEY* at Stretford. From the aqueduct the river flows past Trafford Park and Old Trafford, when it flows north-east over the Pebble Beds of the Bunter, between Old Trafford and Hulme. It receives *Corn* Brook, rising in the Glacial Drift overlying the Pebble Beds between Clayton, Openshaw, and Gorton, thence over the Manchester Coalfield fault, it traverses the Spirorbis Limestone, overlaid by the Permians of Ardwick, and drains the Glacial Drift overlying the Pebble Beds of Plymouth Grove, Chorlton-upon-Medlock, Green Heys, and MOSS SIDE:—the latter contains 421 *acres;* population, 5403; rateable value, 82,000*l.*

River Medlock (tributary of Irwell).

OPENSHAW.—*Acres,* 579; population, 16,152; rateable value, 63,886*l.* Supply of this Authority and Moss Side from Manchester Corporation, where it receives the *Medlock,*

8 miles in length, which, with its tributaries, drains the larger part of Manchester. It leaves the Pebble Beds near Ancoats Hall, and traverses the Upper Coal Measures, by Beswick and Bradford, to the fault throwing in the Pebble Beds at Clayton Dingle. A boring has recently been carried out, and proved a great thickness of water-bearing Permian Sandstone. The Permians crop to the surface, between Clayton Bridge and Ashbridge Farm, where they overlie the Coal Measures; to the south is Droylsden and Fairfield. Eastward of the Permian boundary, the *Medlock* drains a large area of Coal Measures, the workable coals of the middle Coal Measures, coming in at Allthill, striking north and south; the eastern feeders traverse them to the Royley Mine, and cross the Lower Coal Measures, west of their rising, near the top of the Millstone Grit escarpment, overlooking the *Tame* valley.

Manchester Corporation supply:—BRADFORD, population, 16,113; rateable value, 33,814*l*. Droylsden, *acres*, 1144; population, 8679; rateable value, 25,000*l*.

The watershed dividing the *MERSEY* and its tributaries from the *Irwell* and its tributaries, commencing at the junction of the two rivers, ranges along the top of the bluff of Glacial deposits, on which are built the villages of Flixton, Urmston, Stretford, Chorlton-cum-Hardy, and Withington, where it no longer runs parallel to the river, but trends north-eastward by Birch Church, Victoria Park, and Fairfield, forming the northern margin of the *Gore* Brook Basin; thence by Ashton-under-Lyne, where it reaches the top of the steep escarpment formed by the base of the Lower Coal Measures and the Millstone Grit, running west of and parallel to the Pennine anticlinal, which ranges a little west of north as far as Old Delph, where it trends as much as 20° to the west of north through Friar Mere, which has the effect of cutting off the base of the Coal Measures, which the watershed has followed at White Slack, on the south side of Oden Edge, north of which streams draining west rise for the first time east of the fault. The watershed crosses

the fault, and traverses broken masses of Lower Millstone Grit rocks for 2½ miles, until it joins the Pennine watershed, separating the Yorkshire rivers. This portion of the watershed runs along the top of the Millstone Grit escarpment, by Lussley, Mossley, Lidgate, and Besom Hill, at the head of Strine Dale by Badger Edge and High Moor.

The northern feeder of the *Medlock* drains the southern slope of the Oldham ridge and the Coal Measures area around Hollinwood and Merton; to the west these are overlaid by Permian Rocks and Pebble Beds, west of which it enters and eventually crosses the Manchester Coalfield.

Oldham.—*Acres*, 4665; population, 111,343; rateable value, 448,419*l.*, but township, 247,831*l.* more; constant supply of 3,000,000 gallons from tributaries of the River *Medlock* and River *Beal* (Lancashire) and River *Tame* (Yorkshire); Oldham Gaslight and Waterworks Companies Act, 1825, 6 Geo. IV. c. 171; ditto, 1838; 1 & 2 Vict. c. 96; Oldham Corporation Gas and Water Act, 1853, 16 & 17 Vict. c. 42; ditto, 1855, 18 & 19 Vict. c. 47; Oldham Borough Improvement Act, 1865, 28 & 29 Vict. c. 111; Oldham Corporation Waterworks Act, 1870, 33 & 34 Vict. c. 144; ditto, 39 & 39 Vict. c. 180.

The district south of Oldham, between the Chamber Colliery and Fitton Hill, drains into a tributary of the *Medlock*, impounded at Crime Water, which, flowing over the Permians south of Failsworth, joins the main stream at Clayton Bridge.

The watershed between the *Medlock* and the *Irk* ranges through Oldham, west of Hathershaw Hall, by Failsworth and along the Oldham and Manchester high-road, by Newton and Miles Platting, through the centre of Manchester.

Failsworth.—*Acres*, 1073; population, 7907; rateable value, 29,264*l.*; supply constant from *Oldham Waterworks*.

Manchester.—From the infall of the *Medlock* to that of the *Irk* the City of Manchester fronts on to the *Irwell* for 1¼ mile. It covers 4294 acres, and in 1871 had 351,189 inhabitants; in 1881 this number had fallen off nearly 10,000,

being 341,508. The rateable value is 2,225,050*l.* 8*s.* The supply is constant, and from 18 to 19 million gallons a day.* The works at Woodhead, in the valley of Longdendale, 20 miles from Manchester, were carried out under 10 & 11 Vict. c. 203, and 11 & 12 Vict. c. 101. The works can supply 25,000,000 gallons, which, with the present (1879) increasing yearly consumption, will only be sufficient nine years longer.

River Irk.

This stream falls into the *Irwell* near Victoria Station, and flows through a valley cut in the Glacial Drift, overlying the Pebble Beds for about a mile, and then over Permian Marls and Sandstones at Collyhurst, resting on the Coal Measures, at which point it receives *Morris* Brook, rising near Werneth Hall, Oldham, and flowing through Hollin-

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* List of Townships in which the Manchester Corporation supply Water.

Manchester.	Gorton.	Blackley.
Hulme.	Denton.	Burnage.
Chorlton-on-Medlock.	Crumpsall.	Chorlton-cum-Hardy.
Ardwick.	Haughton.	Didsbury.
Newton Heath.	Supplied in detail.	Harpurhey.
Cheetham.	Worsley.	Levenshulme.
Broughton.	Barton-upon-Irwell.	Moss Side.
Pendleton.	Eccles.	Moston.
Beswick.	Prestwich.	Rusholme.
Bradford.	Pendlebury.	Stretford.
Droylsden.	Flixton.	Withington.
Openshaw.	Urmston.	
Supplied in bulk to Local Authorities, who distribute it in the following Townships.		
Salford.	Northenden.	Atherton.
Bollington.	Timperley.	Tyldesley.
Dunham Massey.	Bowdon.	Newton.
Partington.	Altrincham.	Godley.
Carrington.	Hale.	Werneth.
Ashton-upon-Mersey.	Ashley.	Hyde.
Sale.	Baguley.	Stockport (part of).

wood, Wrigley Head, Moston, and Newton Vale, where it traverses the Pebble Beds, the rest of its course being over the Coal Measures. This belt of New Red Sandstone is traversed by the *Irk* west of Harpurhey, from whence it trends westward with the strike of the rock, which it cuts across at Waterside, passing over a narrow strip of Permian on to the Coal Measures, which continue to the source of the river and its feeders at High Crompton, above Royton, and are covered by Drift, traversed by brooks draining the country around Blackley, Alkrington, and west side of Oldham and Royton. Feeders on the right bank drain Thornham Fold and Middleton, which is partly on the main stream, Combershaw, and Heaton. Feeders on the Pebble Beds on the bank drain the district around Cheetham Hill, which is deeply covered with Glacial Drift down to the level of the *Irwell*, good sections being exposed at Higher Broughton.

Middleton and Tonge.—*Acres*, 2323; population, 18,952; intermittent supply from Heywood Urban Sanitary Authority, who charge a very high rate, and give a short supply in time of drought; rateable value, 38,487*l.*

Chadderton.—*Acres*, 3125; population, 16,897; rateable value, 66,000*l.*; nine-tenths of district in limits of Oldham Corporation Improvement Act, 1865 (28 & 29 Vict. c. 311); remaining tenth in that of Heywood Local Board Improvement Act.

Crompton.—*Acres*, 2290; population, 9797; rateable value, 29,254*l.*; partly from Oldham Corporation and partly from springs.

Royton.—*Acres*, 1210; population, 11,433; rateable value, 45,865*l.*; constant supply from Oldham Corporation; storage reservoir is required.

The *Irwell* valley, above the infall of the *Irk*, turns abruptly to the north-west, swinging in a series of long, loop-like curves from side to side of its alluvial plain; this general north-west direction is continued to Farnworth, and continued by its tributary, the *Tonge*, beyond Bolton, both streams in the

main running parallel to and on the downthrow side of a fault, which commences at Poynton, south of Stockport, in the Pebble Beds, ranges by Bramhall and Cheadle, where it brings up a tract of Permian, Withington, Salford, and Pendleton, north of which it throws the Pebble Beds on the east against the Middle Coal Measures on the west as far as Farnworth, after which, by Bolton and Little Bolton, it throws the Lower Coal Measures against the Middle Coal Measures; still further north, at Belmont, it throws the Kinderscout Grits of Anglezark Moors on the west against the Upper Millstone Grits. Here, also, the sources of the *Tonge*, impounded in the Belmont reservoir of the Bolton Waterworks, flow east of and parallel to the fault where it crosses into the *RIBBLE* watershed. The River *Roddlesworth* flows parallel to it as far as its infall into the *Darwen*.

Following the left bank of the *Irwell* past the cliffs of Glacial Drift at Higher Broughton, Castle Hill (an entrenched camp), to Kersall Hill, it receives *Singleton* Brook, draining Sedgley Park and Kersall Moor Racecourse. Other feeders, about 1½ mile in length, drain the Coal Measures of Prestwich, Hardmans Green, Pilkington, and Ringley, east of which the narrow outcrop of the Permian between the Coal Measures and the Pebble Beds, outcrops in the river; west of this the latter overlaps, first the Permian Marls, and then the Sandstones and the Coal Measures, thinning out against the fault at Farnworth.

Prestwich.—*Acres*, 1917; population, 8627; rateable value, 2059*l.* 11*s.* 2*d.* (?); supply partly from *Manchester Waterworks* and partly from *Bury Waterworks*. Rainfall in 1879, at the reservoir, 347 feet above the sea, 34·32 inches; in 1880, 37·95 inches.

The *Irwell* valley at Farnworth turns at an angle of 30 degrees, and trends a little north of east as far as Radcliffe, where it receives the *Roch*, draining 62½ square miles. Following the left bank from the infall of the *Tonge* to that of the *Roch*, small streams drain the Drift-covered Coal Measures

of Outwood, Radcliffe Bridge, and WHITEFIELD or Stand. The latter has a population of 9516, rateable value of 33,373*l.* 7*s.* 6*d.*, and is supplied by *Bury Corporation Waterworks.*

River Roch.

The *Roch* traverses a valley cut for the most part in the sands of the Glacial Drift, resting on Middle Coal Measures as far as Duckworth Fold, where a north-west fault brings up the Gannister series, which continue by Harp Bridge and Heywood to Rochdale, between which points the river is crossed by a series of faults ranging about 35 degrees west of north, mostly with easterly downthrows, which counteract the south-west dip, and continually bring patches of the base of the Middle Coal Measures to the surface.

Whittle Brook, rising south of Heywood, and draining Birch, flows in at Hollins Vale, receiving *Black* Brook, draining Unsworth, at Thurston Fold. Higher up the river, east of Heywood, a feeder comes in rising on Castleton Moor; nearer Rochdale is the *Suddon* Brook, rising near the source of the *Irk*, west of High Crompton, and flowing past the south side of Rochdale. East of the borough is the infall of the River *Beal*, which drains an extensive tract of Lower Coal Measures around Milnrow, Butterworth, and Shaw. Its northern feeders rise near Greenacres, Oldham, and are bounded west by the watershed of the *Irk*. Its eastern feeders rise at the top of the Millstone Grit escarpment, overhanging the Upper *MERSEY* Basin, traversed by the anticlinal fault, except the feeder coming in at New Hey, which rises on the hills of Millstone Grit east of the fault, flowing through Culvert Clough, draining the wild country around Ogden and Helpet Edges.

HEYWOOD.—*Acres*, 3200; population, Heywood Sanitary limits, in 1881, 23,050, Middleton and Tonge Sanitary limits, in 1881, 18,952; rateable value (Heywood), about 96,000*l.*; constant supply of 400,000 gallons and 250,000 to Middleton and Tonge; maximum supply about 1,200,000; under Hey-

wood Waterworks Act, 1846; Amendment Acts of 1855, 1866; Heywood Improvement Act, 1867; Heywood Waterworks Act, 1877. The impounding reservoirs are at Mayden Deane, in the township of Spotland.

Rochdale.—*Acres*, 4180; population, 68,865; rateable value, 222,671*l.* 4*s.* 1*d.*; constant supply of 1,250,000 gallons from reservoirs storing from catchwater drains; works constructing, will be supplied from *Cowm* and *Springhull* Brooks; Rochdale Waterworks Act, 1866, and Improvement Act, 1872. Rainfall in 1879, at 473 feet above Ordnance Datum, 35·77 inches; in 1880, 37·96 inches.

Milnrow.—*Acres*, 2000; population, in 1881, 7022; rateable value, 21,057*l.*; intermittent supply to one-third from Rochdale.

Castleton-by-Rochdale. — Population, in 1881, 4017; rateable value, 2300*l.*; supplied by *Rochdale Corporation Waterworks*.

The *Roch* from Rochdale to its source south of Todmorden flows from north to south; near its head waters rise the Yorkshire and the Lancashire *Calders*. Following its right bank from its source past Littleborough and Smallbridge and Rochdale, it receives the *Spoddon*, rising south of Bacup, and flowing past Whitwroth. The latter has 10,500 inhabitants; rateable value, 37,555*l.*; has a constant supply of 20 gallons a head from *Rochdale Waterworks*.

Littleborough,—*Acres*, 2355; population, 10,405; rateable value, 33,000; constant supply from Rochdale.

West of the infall of the *Spoddon* several small streams drain the steep north bank of the *Roch*, by Chadwick, Bamford, and Birtle. West of the latter place, at Birtle Moor, is an exposure of the Rough Rock of the Millstone Grit, in which runs a subterranean watercourse or spring. A boring in this Grit is now in progress, at a site chosen by myself, above Messrs. Wrigley's reservoir impounding the stream flowing off the Moor, and a supply of underground water has been obtained. Other feeders drain the east side of Bury, and

the district lying between the *Roch* and the *Irwell*, called Red Vales.

Following the left bank of the *Irwell* from Red Vale, it traverses the Middle Coal Measures by Bury south of Walmersley, entering the Lower Coal Measures.

Bury.—Population, 51,582; constant supply of 90,000 gallons per hour from reservoir, storing water flowing by gravitation from moors and other lands; Bury and Radcliffe Waterworks Acts, 1853, 1858; Haslingden and Rawtenstall Waterworks Acts, 1853, 1856, and 1858; Bury Improvement Act, 1872.

Bury Waterworks supply the following with water from a reservoir in the township of Dunnockshaw at Clow Bridge, collecting surface water off cultivated land. Drainage of several houses, and water pumped from a coal-mine where 30 men are employed, finds its way to the reservoir; the water is not filtered; under Haslingden and Rawtenstall Waterworks Act, and the Bury Improvement Act, 1872:—Rawtenstall, *acres*, 1667; population, in 1881, 12,571; rateable value, 38,127*l.*; supply intermittent. Haslingden, *acres*, 3627; population, in 1881, 14,333; rateable value, 44,818*l.*; supply intermittent.

Following the left bank of the *Irwell* from Bury north, it crosses a north-west fault bringing in the Millstone Grits at Walmersley, through which it has cut a deep and wide valley, by Summerseat, Ramsbottom, Edenfield, and Rawtenstall; numerous feeders with steep fells come down from the hills above at Harden Moor, Whittle Hill, and Coupe Lowe. The beds of Millstone Grit lie very flat in this group of valleys, Third Grits occupying the bottom of the principal valleys, Shales and Second Grits occurring higher up, and the Rough Rock, or the Lower Coal Measures, capping the hills, which form the remarkable group of valleys of denudation, the eastern portion of which is known as the Forest of Rossendale.

Bacup.—Population, 25,033; rateable value, 83,017*l.*;

constant supply, except in drought, from *Rossendale Waterworks*, who supply one-third of the district from their reservoir; Rossendale Waterworks Act, 1853, Amendment Act, 1854, 17 Vict. c. 18; the Company should be compelled to filter the water, and have not the means of supplying the whole of the district within their limits of supply. Rainfall in 1879, at Calf Hey, 800 feet above the sea, 54·75 inches; in 1880, 46·10 inches.

A strong feeder, rising at the top of the Millstone Grit at Hopton Park, drains Higher Booth, Goodshaw, and Lower Booth, and falls into the *Irwell* at Rawtenstall. West of this valley a tongue of high ground capped with Rough Rock forms Cribden Moor, on the western slope of which are the well-known quarries in the Haslingden Flags or Second Millstone Grit, which gives the name to this horizon of the Grit. Between the Rough Rock and the Flags is a bed of Shale, and another bed underlies the Flags. Between Haslingden and Cribden Moors in the Haslingden valley, drained by *Swindel* Brook, which receives on its right *Mill* River rising under Pike Low, the stream is impounded above Holder's Wood. Another feeder drains Musbury valley, on the heights of which are large Flag quarries; the united stream falls into the *Irwell* at Tottington High End. Further south the right bank of the *Irwell* drains the hills above Holcombe and Rawtenstall, and receives *Holcombe* Brook, rising in the cliff of Rough Rock known as the "Ratchers,"* at Bull Hill, which is traversed by the watershed separating the *Upper Irwell* basin from that of *Bradshaw* Brook, tributary to the *Tonge*.

Numerous tributaries drain the Drift-covered Coal Measures occupying the right bank of the *Irwell*, around Tottington, Elton, Ainsworth, Radcliffe, Bradley Fold, and Little Lever, south of which place the *Irwell* receives the River *Tonge*.

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* Professor Hull, M.A., F.R.S., 'Memoir on the Geology of Bolton,' in 'Memoirs of the Geological Survey.'

Radcliffe.—*Acres*, 2300; population, 16,263; rateable value 71,402*l.*; constant supply from *Bury Corporation Waterworks.*

Little Lever.—*Acres*, 809; population, 4413; rateable value, 18,215*l.*; intermittent supply from Bury; high service reservoirs and larger mains required.

River Tonge.

This stream drains entirely a Coal Measure and Millstone Grit area. Following its left bank to its source, it flows over Middle Coal Measures to beyond Bolton. Just below that town it receives *Bradshaw* Brook, which runs nearly parallel to it, draining the county round Turton, Entwistle, Bradshaw, Harwood, and Tonge, rising on the outliers of Millstone Grit and Gannister, south of Over Darwen. At Entwistle it is embanked for *Bolton Waterworks.*

Turton.—*Acres*, 4613; population, 5653; rateable value, 21,104*l.*; supply from Bolton Corporation, under Bolton Improvement Act, 1850, and wells.

The *Tonge*, north of the infall of the brook, drains the Middle Coal Measures as far as Astley Bridge, where its direction is continued by the River *Eagle.* At Eagley Bridge this stream enters the Millstone Grit, flowing past Walmsley and Belmont, between which and Longworth is the Bolton Corporation reservoir.

The dip of the Millstone Grit is westerly on both sides of the fault traversing the valley. The watershed at the col at the northern end of the valley is 968 feet above the mean level, rising to 1215 at Bromley Pastures, and 1450 at Winter Hill.

River Croal.

At Astley Bridge the *Tonge* turns westward, crossing the Bolton and Pendleton fault between Sharples and Halliwell. Parallel with this stream flows an important tributary, the River *Croal*, rising at Red Moss below the Rivington reservoirs,

which is traversed by the watershed dividing the basin of the *Douglas* flowing into the estuary of the *RIBBLE* from that of the *MERSEY*. From the surplus waters of this Moss rise the *DOUGLAS* and *Middle Brook*, the head waters of the *Croal*, on its southern margin. The *Croal* flows through a broad valley in the strike of the Coal Measures nearly corresponding to the division between the lower and upper divisions of these Measures. It has been filled up with deposits of Glacial Drift, Sand, and Gravels overlaid by Boulder Clay, which have to a great extent been re-excavated. These sands are valuable in storing up the water they absorb during heavy rains, and delivering them gradually in times of drought.

In the quarries in the Rough Rock, on the hill above Horwich, strong feeders of water were met with, which are abstracted by a syphon for the garden of an adjacent house.

The watershed between the *DOUGLAS* and *Middle* Brook at the highest part of the Peat Moss is 367 feet above the mean sea-level; from Red Moss it ascends Blackrod Hill, reaching 466 feet at Highfield House, when it trends northward, and is joined by the watershed separating the *Croal* valley waters from tributaries of the *MERSEY* flowing south of Leigh and Hindley. The watershed bounding the *Croal* valley follows the crest of the hill from Blackrod, by Wingates, to West Houghton, along which was carried a Roman road, thence eastwards between Dean and Little Hulton, rising to 550 feet at Top Caw. From this point the *Croal* watershed trends north-east past Rumworth to the infall of the river into the *Tonge* at Bolton.

Bolton.—*Acres*, 1162; population, 105,422 (of water limits outside borough, 64,408?); two service reservoirs; four storage reservoirs; Belmont gathering-grounds in townships of Sharples, Longworth, and Entwistle, Bradshaw in township of Turton; constant supply of 2,625,000 gallons in the borough; 1,875,000 outside; rateable value, Borough 361,000*l.*; outside water limits (roughly) 313,000*l.*; works carried out under Bolton Improvement Acts, 1854, 1864, and 1865; filtering beds are required.

Annual Amount of Rain and Evaporation at Bolton, during the 50 years ending Dec. 31st, 1880 (from the register of H. H. Watson, Esq., F.C.S., &c.), at the Folds, 286 feet above the sea.

	Rain.	Evapo.		Rain.	Evapo.
	Inches.	Inches.		Inches.	Inches.
1831	62·30	22·07	1856	49·23	20·03
1832	53·77	22·35	1857	40·19	22·52
1833	51·70	24·23	1858	41·02	22·21
1834	43·98	24·18	1859	46·02	18·99
1835	46·44	23·78	1860	57·66	21·94
1836	53·78	24·36	1861	44·91	19·45
1837	42·25	17·12	1862	53·43	17·80
1838	47·85	20·16	1863	53·75	19·04
1839	45·26	24·71	1864	42·74	20·31
1840	45·03	23·79	1865	37·51	20·24
1841	53·87	24·51	1866	59·20	19·03
1842	38·63	24·69	1867	45·27	18·88
1843	49·40	24·02	1868	46·34	23·41
1844	34·63	22·60	1869	49·00	19·24
1845	48·11	23·39	1870	43·47	18·92
1846	40·82	24·16	1871	40·93	18·52
1847	52·32	22·76	1872	57·59	17·84
1848	54·05	22·02	1873	42·69	18·21
1849	47·77	26·21	1874	48·67	18·59
1850	47·99	29·23	1875	43·94	18·94
1851	41·89	26·40	1876	46·10	20·09
1852	55·19	35·93	1877	60·33	15·97
1853	36·88	23·85	1878	45·79	18·95
1854	45·46	21·17	1879	42·82	24·60
1855	36·19	17·86	1880	43·36	19·72

The mean of 49 years, ending 1879, was 42·82 inches, and the mean evaporation 24·64 inches.

Rainfall at Bolton Waterworks, taken by Mr. R. H. Swindlehurst in 1880.

Belmont, 800 feet.	Heaton, 500 feet.	Entwistle, 700 feet.
58·20	41·80	53·50

The mean fall at Belmont for 38 years ending 1880 was 56·26 inches. Mean fall at Heaton for 22 years was 44·37 inches. Mean fall at Entwistle for 13 years ending 1880 was 54·85 inches.

Astley Bridge.—*Acres*, 1162; population, 5614; rate-

able value, 23,777*l.*; supply from Bolton, constant, under 7 Vict. c. 74.

Little Hulton.—*Acres*, 1706; population, 5724; rateable value, 22,610*l.* 18*s.* 9*d.*; constant supply of 100,000 gallons from Bolton, under their Corporation Act, 1872.

The remaining tract of country in the *Irwell* Basin undescribed is bounded to the west by the watershed of the *MERSEY*, which ranges south-east from Top of Caw to Little Hulton, from which it runs south down the dip of the Middle Coal Measures, by Ellenbrook, crossing the Permian outcrop east of Astley Green it enters the drift-covered plain, resting on the Pebble Beds and surmounted by Chat Moss, which it crosses south-westward to Olive Mount, then south-eastward to Lower Islam, where it falls into the junction of the *Irwell* with the *MERSEY*.

Following the right bank of the *Tonge*, from Bolton, it flows past Great Lever and Darley Hall to Farnworth, where it falls into the *Irwell*, which thence assumes its direction, flowing parallel with the Great Bolton fault on its downcast side. There can be little doubt the direction of the stream is governed by the fault; the rock is only seen in the bed of the stream, the valley above being entirely excavated in Glacial Drift. The strike of the rocks on both sides of the fault is east-south-east, the base of the Gannister series intersecting the fault at Bolton Moors, that of the Middle Coal Measures at Moses Gate, the outcrop of the Rams and Brassy Mines at Clifton, that of the Worsley 4-feet coal between that place and Pendlebury, the Permian at Pendleton, the river side of which is on the Pebble Beds, which rest directly in this district on the Permians, the Lower Mottled Sandstone being absent.

Farnworth.—Population, 20,701; rateable value, 59,500*l.*; supplied from *Bolton Corporation Waterworks*, under Bolton Improvement Act, 1850.

Kearsley.—Population, 7241; rateable value, 20,095*l.*; constant supply from Bolton Corporation.

Swinton and Pendlebury.—*Acres*, 2165; population,

in 1881, 18,108; rateable value, 66,907*l.*; constant supply from Manchester.

SALFORD.—*Acres*, 1329; population, 176,233; rateable value, 372,218*l.* 10*s.*; (Salford District) constant supply of 1,840,000 gallons from Manchester Corporation, who are bound to supply Salford Corporation in bulk with quantity not exceeding 2,000,000 gallons a day; Broughton and Pendleton are parts of the Borough of Salford, but are supplied by Manchester direct.

A minor watershed ranges from Little Hulton, by Moss Side, Clifton Moss, Newtown, and Pendlebury, separating the tributaries of the *Irwell*, flowing in above the turn of the river at Salford, from those coming in to the south, which flow first over the Coal Measures of Newtown, Roe Green, Swinton, and Worsley, and then over the Pebble Beds capped by Glacial Drift of Eccles, Monton, Hazelhurst Green, Patricroft, and Barton, then over the Upper Mottled Sandstone at High Islam, where the edge of the Chat Moss advances to no great distance from the valley margin.

Rainfall at Eccles Observatory, 137 feet above the sea:—

1876	38·35	1877	45·17

Mr. Mackereth, F.R.A.S., states the average rainfall of Eccles to be 36·03 inches for 17 years, ending 1877.

At Barton the Bridgwater Canal crosses the *Irwell*, from which it is carried to Worsley, and thence westwards, skirting the northern edge of Chat Moss, to Leigh. Population of BARTON, Eccles, Winton and Monton, 21,785.

Between High and Low Islam the surface of the rock is beneath the river-bed, and the banks or bluffs of the valley are formed entirely of Glacial Drift, the two Boulder Clays being separated by the Middle Sands overlying the Upper Boulder Clay.

RIVER MERSEY—Right Bank.

Following the right bank from the infall of the *Irwell* at Lower Islam, the river crosses the base of the Lower Keuper

Sandstone. The best sections, showing coarse beds, are seen on the opposite side of the river at Partington. At Cadishead they are obscured by Boulder Clay. Keuper Sandstones are, however, visible in the remarkable valley of *Glazebrook*, which falls into the *MERSEY* at Hollinfare. It is cut in Glacial Drift resting on rock, and is capped by the peat of Chat Moss on both sides, once evidently continuous, and the disruption is stated to be of no great antiquity. It drains an area of not less than 70 square miles, of which the northern 49 consist of Drift-covered Middle Coal Measures, and the southern of 21 miles of Permian Sandstone and Marls, and at West Leigh and Astley, of Pebble Beds and Upper Mottled Sandstone. The latter is Drift-covered, and capped with the peat of Chat Moss, Holcroft Moss, and Glazebrook Moss; the only permeable beds therefore being the Permian and Pebble-Bed Sandstone, fringing the southern margin of the Coalfield. The northern feeder rises on the Haigh and Blackwood watershed at a height of little less than 500 feet, then, flowing through Scot Lane valley and the Drift gorge of *Borsden* Brook, descends to 240 feet at Hindley Vale, to 150 feet at Hindley, thence to Platt Bridge at 96 feet, and under the Wigan and Leigh Canal at Bamfurlong, where it trends eastwards and follows the strike of the Pebble Beds, passing south of Leigh, as *Plank Lane* Brook, to Hawkhurst, where it receives the Leigh and Tyldesley feeder, *Hindford* Brook, from the north and *Shaw* Brook from the east, traversing the strike valley from the opposite direction to *Plank Lane* Brook, and like it flowing along the boundary of the Pebble Beds and Upper Mottled Sandstone, which latter, as before stated, is Drift-covered.

Another Coal Measure feeder rises near the *Croal* watershed at Wingates, 455 feet above the sea, flows by West Houghton, Fickley Green, and West Leigh, and falls into *Plank Lane* Brook. *Hindsforth* Brook rises under Top of Caw, 550 feet above the sea, and flows by Middle Hulton, Tyldesley, at 130 feet, with a feeder from Atherton, and Leigh, Bedford, south of which it joins the two streams already mentioned.

The country around Little Hulton, Peel, Ellenbrook, and Astley drains into *Shaw* Brook.

These three brooks, draining 49 square miles of country consisting of strata in the main of an impermeable character, and further overlaid by impermeable beds of Boulder Clay, receive an annual rainfall of at least 40 inches, which, considering the sharp gradients of the upper part of the district, must flow off rapidly, and allow little time for evaporation. In such a district, half the fall may fairly be expected to run off, or 20 inches per annum, which would give a daily average of 800,000 gallons per square mile, or 39,250,000 gallons a day for the drainage area, or, with a run-off of only 10 inches, a daily average of 19,500,000 gallons, or 28,000,000 gallons for the entire drainage area. No such quantity is discharged by *Glaze* Brook, and it is interesting to inquire where the water is abstracted.

The drainage of the Coal Measure tract is discharged at Abram, West Leigh, and Astley respectively, into a brook running over the Pebble Beds of the Bunter, which are but little covered with Glacial Drift, and are of an exceedingly porous character. The dip is southerly, and the Coal Measures have been proved at Winwick and Parkside to underlie them at no great depth. The southerly dip continues on the Cheshire side of the river, bringing in successively the Lower Keuper building stones, the Waterstones, and the Keuper Marls, which latter occupy a deep basin, the centre of which is under Northwich, the Lower Keuper and Bunter Beds reappearing on the Market Drayton and Whitmore side of the basin. These sandstones will be fully charged with water under the whole of this basin, beneath the salt-bearing Marls. In times of excessive rainfall the water-level in the rock near the outcrop will be raised, and at such times will be above the plane at which it is crossed by the *MERSEY*, in which case surplus waters will issue as springs in the bed of the *MERSEY*. This water will have slowly filtered through the rock underlying the Glacial Drift beneath Chat Moss. The excess of rainfall that the mosses cannot absorb will exude

on their edges in all directions, that issuing on their northern margin will flow into the stream to the north, be partly absorbed, and carried back southwards in the rock beneath, the overflow finding its way into the bed of the *MERSEY*, the remainder to the stores accumulating under the Cheshire Saltfield.

Bryn Moss, on the watershed between the basin of the *DOUGLAS* and the *Borsden* Brook basin, has only an elevation of 102 feet. The valley, in which is Bryn Moss and other adjoining mosses, slopes almost imperceptibly in both directions, and must be regarded as the natural head of the *DOUGLAS* Valley, rather than the narrow gorge in which the *DOUGLAS* flows, entering the main valley on the east side of Wigan. If this view be correct, the Bryn Moss Valley must have been excavated by a stream occupying the Black Lane Valley, and flowing from the east, receiving first the *Borsden* Brook waters and then those of the *DOUGLAS* above Wigan. That this was the case in pre-Glacial times there can be little doubt, and it probably flowed from Astley Green, at the epoch preceding the growth of the peat mosses.

Looking to the great depth of the valley of the *DOUGLAS* between Ashurst Beacon and Harrock Edge, it is probable that the pre-Glacial *DOUGLAS* rose at a very considerable elevation, which would be the case if the *Irwell* at that period was not a tributary to the *MERSEY*, but continued its trend from Old Trafford to Eccles and Patricroft, into the Plank Lane, Bryn Moss, and *DOUGLAS* Valley, following the line taken by the projectors of the Wigan and Leigh Branch of the Bridgwater Canal.

West Houghton.—*Acres*, 4341; population, 9197; intermittent supply from Bolton Corporation at 6*d.* per 1000 gallons, delivered at township boundary; rateable value, 36,728*l.*

Hindley.—*Acres*, 3611; population, 14,667; rateable value, 49,403*l.*; constant supply of 68,152 gallons from Bolton Corporation, by agreement for five years, under Leigh and Hindley Water Act, 1876.

ATHERTON.—*Acres*, 2426; population, in 1881, 12,602; rateable value, 40,000*l.*; supply of 1,000,000 gallons per week from Manchester (maximum supply of 1,450,000 gallons), through Tyldesley; Public Health Act, 1848.

TYLDESLEY with SHACKERLEY.—*Acres*, 2489; population, 9953; rateable value, 40,949*l.*; supply from Manchester of 350,000 to 500,000 gallons, including that supplied to Atherton.

LEIGH.—*Acres*, 6191; population, 21,733; rateable value, 65,064*l.*; water supply from Atherton Local Board by agreement for 7 years, from the 1st of January, 1876, and from Bolton Corporation by agreement for 6 years, from the 1st of March, 1877; Public Health Act, 1875, and Leigh and Hindley Local Board Water, 1874.

Between the infall of the *Glaze* Brook and Hollinfare the river crosses the Rosthern and Warburton fault, which, in the Wigan Coalfield, becomes the Great Standish fault, with an easterly downthrow. West of it, to Warrington, the valley runs through the top beds of the Upper Mottled Sandstone, which does not appear to crop in the river bed. The Upper and Lower Boulder Clay, separated by the Middle Sand, are seen in the valley banks by Martinscroft Green, Woolston, and Poulton. To the north, Risley, Woolston, and Rixton Mosses cover several square miles, the peat resting on the Shirdley Hill Sands, which more or less overlie the Boulder Clay at Padgate and Croft. West of the latter the Pebble Beds come to the surface, and are drained by *Kenyon* Brook, flowing by Orford Green, where it is known as *Black* Brook.

WARRINGTON.—*Acres*, 5042; population, 41,456; rateable value (Borough), 146,976*l.* 18*s.*; constant supply of 800,000 gallons from Water Company, who have two distinct sources of supply: (*a*) reservoir of 16 acres at Appleton, in Cheshire, storing the surface waters flowing off about 1360 acres of cultivated land; (*b*) covered reservoir at Winwick, north of Warrington, storing water pumped from artesian wells in the Pebble Beds, at which works are still being carried out.

The Waterworks Companies Acts of 1840, 1849, 1855, 1868, and 1878. Rainfall at Friar's Green, Tocon Hall, 33 feet above the sea:—

1878.	1879.	1880.
34·25	30·68	34·34

In boring at Winwick the deposits penetrated by Mr. Timmins were: Drift, 30 feet; New Red Sandstone, 310½ feet; Upper Coal Measure, Marls and Sandstone, 33½ feet; Limestones and Marls, 37 feet (Ardwick Beds).

The dip of the Pebble Beds in the neighbourhood is to the south-east and south, at low angles. In Nos. 1 and 2 shafts the strata consist of soft red moulding sand without pebbles, very easily worked. No. 3 shaft exhibits characteristic Pebble Beds, the current planes being covered with dark mica; the rock is hard, and contains pebbles. No. 4 shaft, near the Spa Well, also is in undoubted Pebble Beds, though moderately hard, but contains many pebbles.

A drift, or level, is being driven to this shaft from the pumping station 1200 yards distant, which will doubtless throw much light on the structure of these Sandstones. A powerful spring of water was met with in No. 4 shaft, at a depth of about 90 feet from the surface.

The level of the Parkside wells of the North-Western Railway will be about 110 feet, that of Winwick pumping station 125 feet, that of the Spa Well about 96 feet, that of the Dallam Lane Forge well about 43 feet. Between Golborne and Parkside the Pebble Beds occur, dipping east; from Parkside to Spa Well they continue, but gradually change their direction of dip to south-east, as is well seen at Middleton Hall Quarry, near Spa Well. Had not this change of strike taken place the base of the Pebble Beds would have cropped out north of Winwick, instead of which they occupy a considerable tract around Golborne, and the thickness of Triassic strata at Parkside would have been much less than at Winwick, 1¼ mile to the south, the strike

of the rocks nearly coinciding in direction with a line drawn between the two wells.

Between the Winwick pumping station and Dallam Lane Forge, 2½ miles distant, this is not the case; the Pebble Beds at Hulme Delf, south of Winwick, dip south, or directly at the Dallam works. The dip varies at different quarries from 4° to 8°. Taking it at 4°, and the base of the Trias at Winwick at 215 feet below Ordnance Datum, and assuming the surface of the Coal Measures beneath the Trias to correspond to the amount of dip, the base of the Trias could be carried down 1000 feet at Dallam Lane Forge, or 1215 feet below Ordnance Datum, and 1258 feet below the surface.

The boring at Dallam Lane actually penetrated of this depth 880 feet, the lowest beds met with being 70 feet of soft Lower Mottled Sandstone, with the millet-seed grain, occurring immediately beneath (pebble-bearing) Pebble Beds, so that these soft beds evidently belong to the uppermost portion of the Lower Mottled series. These at Winwick reach a thickness of more than 200 feet, and at Bootle boring of more than 300 feet, in the latter case without their base having been reached, so that they may possibly be 350 feet thick under Warrington, in which case their base will be 1230 feet beneath Dallam Lane Forge, which closely agrees with the calculation of the probable position of the base of the Trias, based upon the observed dips at Winwick. There is therefore strong evidence to believe that the Coal Measures underlie Warrington at a depth of 400 yards, but at what angle and in what direction they dip there is no evidence to show. The highest coals of the Wigan Coalfield, the "Ince Mines," are striking nearly south, between Town Green, Ashton, and Edge Green, Golborne, and, did no fault intervene, their southern prolongation would pass through Newton Bridge and Great Sankey, but it is repeatedly thrown back westwards by faults, with westerly downthrows, so that the Coal Measures between Winwick and Sutton are entirely

measures lying above the Lyons Delf of St. Helen's, and probably in great part belong to the Upper or Manchester Coalfield. In the centre of this tract a colliery has been sunk at Bold Moss, east of St. Helen's Junction, and several coal-seams have been passed through. These have been supposed to be identical with the upper seams of the St. Helen's field; but, after comparing the section drawn to scale with the neighbouring collieries, I am inclined to think that these coals are on a higher horizon, and probably belong to the Upper Coal Measures. Progressing westwards, the first fault with an easterly downthrow is that passing through Whiston, which, with that passing Sutton Heath, throws in the remarkable trough of New Red Sandstone, extending from Rainhill to Eccleston Hill, and it will be noted that it is in this triangle that the small tract of Upper Coal Measure Limestone is brought by faults to the surface at Huyton, with the normal north-east and south-west strike.

Sankey Brook.

The *MERSEY*, after making two sharp turns past Warrington, receives the drainage of *Sankey* Brook. Following its left bank, up stream, through a shallow valley in the Boulder Clay more or less covered with Shirdley Hill Sand, it receives *Spa* Brook, which rises at Spa Well at Arbury on the Pebble Beds, and falls into the main stream at Hulme. Between Winwick and Wargreave is the infall of *Newton* Brook, which, after receiving a feeder from St. Oswald's Well, trends north past Newton-le-Willows (Newton Bridge Station and North-Western Railway) to Golborne Park, where it is impounded in Golborne Dale. The western feeder of *Newton* Brook rises near Haydock Lodge; an eastern feeder followed up stream, after twice crossing under the railway, trends north-westward by Golborne and Ashton-in-Makerfield, as *Mullingford* Brook; crossing the Great Pemberton fault, it enters the Wigan Coalfield, and, flowing past Downall Green, rises on the eastern slope of Billinge village hill.

The Haydock Lodge stream receives a feeder draining the

Coal Measure country around Haydock, which is covered with thick deposit of Glacial Drift.

West of the infall of *Newton* Brook, *Sankey* Brook skirts Newton Common and Racecourse, and soon after passes on to the Coal Measures. An important feeder comes in on the left bank, one branch of which rises on the west side of Billinge Beacon, traversing the Gannister series, which are extensively worked for flags, crosses the Billinge fault throwing in the middle Coal Measures, and is impounded at Caw Mill Dam. The other branch rises in the extreme north-western corner of the *MERSEY* watershed, at Bickerstaffe east of Ormskirk, flowing past Rainford and the northern side of St. Helen's. At Rainford good sections are exposed of a deep red-coloured fine-grained current-bedded sandstone, referred by Mr. Binney to the Permian, and by Professor Hull to the Lower Mottled Sandstone; *Windle Brook* rises in it.

St. Helen's.—*Acres*, 12,078; population, 57,234; rateable value, 211,642*l.*; constant supply from wells in Pebble Beds at Eccleston Hill, and Lower Mottled Sandstone at Whiston, supply 1,750,000 gallons of water daily, stored in two covered service reservoirs. A small supply of water, used for trade purposes, is derived from surface drainage, total supply available, 2,000,000 gallons; works under St. Helen's Improvement Acts, 1851, 1855, 1869, and Public Health Act, 1875.

Strong feeders of water occur at Bold Hall and Collins Green collieries, water from the latter is used as a supplemental water supply for St. Helen's. The Sankey Canal is carried on the right bank of *Phipp's* Brook from St. Helen's, and has its outlet at Fiddler's Ferry. Following the *MERSEY* watershed from Bryn Moss, it crosses the Middle Coal Measures to the Gannister beds of Billinge Beacon, and runs along their strike to near Pimbo Lane, then trends westward, and descends to 272 feet near the source of the River *Tawd*, to 240 feet at Causeway Moss near Blaguegate, and 232 feet at Four Lane End, Bickerstaffe, where the watershed turns and trends southward, still further descend-

ing, being 200 feet at Bickerstaffe Wood, 150 feet at Rainford Station, which level is continued in Barrow Nook Moss, from which the watershed begins again to ascend, being 185 feet at Massborough Hall and 264 at Knowsley Chase.

BILLINGE. — *Acres*, 4591; population, 3882; rateable value, 15,702*l.* 17*s.* 4*d.*; scheme sanctioned by Local Government Board, to yield 20 gallons per head, but no provision is made for any great increase of population; Public Health Act, 1875.

ASHTON-IN-MAKERFIELD.—*Acres*, 6249; population, 9825; rateable value, 52,414*l.*; works constructing under Ashton Local Board Act, 1875; constant supply of 180,000 gallons from reservoirs storing water off cultivated land; wells in New Red Sandstone.

HAYDOCK.—Population, 5863; wells and tanks; rateable value, 19,335*l.* 2*s.*

NEWTON-IN-MAKERFIELD. — *Acres*, 3103; population, 10,580; rateable value (for water purposes), 24,380*l.*; supply constant of 46,000 gallons from London and North-Western Railway Company, supplied by meter to sanitary authority; Local Government Act, 1858; Newton Improvement Act, 1855.

Sankey Brook drains 62 square miles, of which 36 consist of Coal Measures largely overlaid by Glacial Drift, and 25½ of New Red Sandstone and Permian Sandstone occurring on three sides of the Coal Measure area. Taking 30½ miles of the former and 5½ of the latter as impermeable, there would be a total of 36 miles on which all water would be thrown off. Taking the rainfall at 36 inches per annum and evaporation at 16, a balance of 20 inches per annum would be run off, or 800,000 gallons per day per square mile, or a daily run-off, due to the Coal Measures, of nearly 37,000,000 gallons. A large portion of this volume is absorbed by the Pebble Beds over which these streams fall, which absorb in this area not less than 20 inches of the annual rainfall.

Bold Park and Fairs Green are drained by two feeders uniting and forming *Whittle* Brook, flowing past Great Sankey, and falling into the *MERSEY* at the infall of *Sankey*

Brook. At Penketh another feeder comes in, *Haltons* Brook. Between this brook and Widnes is the district of Cuerdly, which is drift-covered, but at Farnworth, Cronton, Appleton, Widnes, and Ditton several exposures of Pebble Beds crop to the surface, and numerous small wells prove the permanent water-level in the rock to rise to 50 feet above the mean level of the sea.

At Runcorn the two sides of the valley contract to form Runcorn Gap, only a quarter of a mile in width, with rock on both sides. Mr. Mellard Reade has pointed out that borings made on the Lancashire side prove the rock to suddenly sink on the north side 141 feet, through which depression, since filled up with Glacial Drift, he believes the river to have run in pre-Glacial times.

A remarkable tract of New Red Sandstone is intruded by faults, between the Coal Measures of Whiston and Sutton; it consists of Pebble Beds resting on Lower Mottled Sandstone, the latter cropping north of Eccleston Hill, and on the western margin adjoining the Halsnead fault, thence continuing south by Stocks Lane to Hough Green.

At Widnes is Messrs. N. Mathieson and Co.'s No. 1 well at east end of the works, 10 feet above Ordnance Datum, 4 feet 6 inches diameter and 30 feet deep; borehole 366 feet from surface, 6 inches diameter. Normal water-level 6 feet from surface. Pumping level (after 5 hours) 25 feet from surface. Yield 2000 gallons per day of 12 hours.

West of Runcorn Gap, *Ditton* Brook falls into the river. Its left bank drains Ditton and Tarbuck, where it crosses the Huyton fault, and enters the Upper Mottled Sandstone, and becomes *Tarbuck* Brook, dividing at Netherlee Bridge; the eastern rising in and traversing the Coal Measures near Huyton for a short distance, the western, *Childwall* Brook, rising near Roby. The right bank drains Childwall, Gateacre, and Acrefield, and the eastern slope of Much Woolton and Little Woolton. A well at Roby Hall has a top water of 80 feet above Ordnance Datum, that of Oakfield Quarry is 93, and is dry when Dudlow Lane well, 2¾ miles distant, is at work,

with the Croxteth fault intervening. The top water-level at the Belle Vale boring is 52 feet, that of Grange Lane 72, and that of Netherlee 37 feet.

The drift-covered promontory of Hale is drained by *Rams* Brook, rising at "Old Hut" and flowing south-east, falling into the *MERSEY* opposite Western Point.

West of Hale Head, by Hale Heath, Dungeon Point, Oglet Point, and Red Brow, banks of Boulder Clay form the coast-line, and they are only broken by small streamlets. The *MERSEY* watershed is drawn by the Ordnance Survey as terminating at Red Brow and running by Speke, Much Woolton ridge, Waverton Knotty Ash, Huyton, to Knowsley Park, to which point it has already been traced.

Widnes.—*Acres*, 3300; population, 24,919; rateable value, 90,303*l.* 17*s.*; supply of 1,440,000 gallons pumped daily into service reservoir from wells in the New Red Sandstone at Stockswell, where the water formerly rose to the surface 62 feet above Ordnance Datum, at Netherlee Bridge, where the water stands at 37 feet above O.D., and at other places in the Childwall valley; Widnes Improvement Act, 1867, and Widnes Local Board Act, 1875.

Liverpool Corporation Waterworks supply:—Garston, *acres*, 7568; population, 10,131; rateable value, 54,963*l.* Childwall, *acres*, 996; population, 207; rateable value, 1980*l.* Huyton with Roby, *acres*, 2917; population, 4060; rateable value, 37,342*l.* 2*s.* 1*d.* Little Woolton, *acres*, 1159; population, 1128; rateable value, 14,052*l.* Prescot, *acres*, 268; population, 6418; rateable value, 11,947*l.*

CHAPTER XXXI.

SOUTH-WEST LANCASHIRE BASIN.

Garston to Crosby Streams (*XLVII., in part*).

This area of 33 square miles is included by the Ordnance Survey in that of the basin of the *ALT*. It is entirely occupied by Triassic formations, ranging from the Pebble Beds up to the Waterstones of the Keuper. The central ridge, on the western slope of which the city is built, consists of Pebble Beds, cut off to the west by the Everton fault, throwing in the Keuper building stone, well seen in the approach to Lime Street Station from the tunnel. To the east they dip under the Upper Mottled Sandstone, which occupies a belt of country extending from Toxteth Park to Walton-on-the-Hill, east of which another strike-fault brings in the Pebble Beds of Much Woolton, and Childwall.

In 1835, Sir Roderick Murchison* gave the following classification of the Red Rocks overlying the Coal Measures:—

1. Red and Green Marls	*Keuper.*
2. Sandstone and Conglomerate	*Bunter.*
3. Calcareous Marl and Conglomerate ..	*Zechstein.*
4. Lower Red Sandstone	*Roth-todt-liegende.*

In 1837, the Rev. Professor Buckland ascribed the Warwick Sandstones, with their reptilian fauna, to the age of the Keuper of Germany, and compared them with the building stones of Stuttgard and Sinzheim, near Heidelberg. These Warwickshire sandstones consist of either soft, white, or grey sandstones, more or less thin-bedded and interstratified with Marl, with a slightly conglomeratic base, resting indiscriminately on Permian or Coal Measures, and may be considered as the typical English "Waterstones."

In papers read before the British Association in 1842, the Geological Society of London in 1846, and at Manchester

* 'Proc. Geological Society,' London, vol. ii.

at a still earlier date, Mr. Binney, F.R.S., was the first to work out the chief outline of the classification of the Lancashire and Cheshire post-carboniferous red rocks, the sequence being:—

Trias (Murchison):—

1. *Red Marl* (Ormerod)	(*a*) Red and Variegated Marls ..	1000 feet.
	(*b*) Gypsum and Saliferous Marls	800 „
	(*c*) Waterstones	440 „
2. *Bunter Series*	Maximum thickness	600 „
Permian. 3.	Red and Variegated Marls and Magnesian Limestone ..	210 „
4.	Lower New Red Sandstone.. ..	120 „

In this classification I am inclined to think that the term "Waterstones" does not include the compact Lower Keuper building stone and grit, which was evidently classified with the Bunter Beds beneath in the papers by Mr. Ormerod and others of the period. This restricted use of the term "Waterstones" is one which it is of importance to maintain, as they, probably, and not the building stones beneath it, are the equivalent of the typical Waterstones of Warwickshire.

In 1854, Professor Hull laid a paper before the British Association, showing the Bunter Beds were capable of a triple sub-division, massive sandstone, with pebbles or Pebble Beds, intervening between an Upper and Lower Mottled Sandstone. Occasionally the Pebble Beds are only soft sand with shingle, and the Mottled Sandstone beneath it gradually thins out eastward, its maximum development being in the Shropshire area. In later papers he showed the Lower Keuper moves transgressively over the eroded Bunter Sandstones on to older formations.

Liverpool.—*Acres*, 5211; population, 552,425; rateable value, Urban Sanitary District (Borough), 3,194,299*l*. After deducting three-fourths of the assessments from properties entitled to this deduction for water-rate purposes, the amount is 2,980,391*l*. The works were carried out under the following Local Acts:—10 & 11 Vict. c. 261; 13 & 14 Vict. c. 80; 15 Vict. c. 47; 25 & 26 Vict. c. 107; 29 & 30 Vict. c. 126; 34 & 35 Vict. c. 184. The works cost 2,256,808*l*., including the cost of works purchased from two private

Companies in 1848; also the cost of the entire system of pipes, &c., for distribution. According to the Corporation authorities, there will be a deficiency of water supply of 7,000,000 gallons a day in the year 1885. To meet this, the Corporation obtained powers from Parliament last year to abstract the head waters of the *SEVERN*.

The present supply is 17,750,000 gallons, the average supply is 15,081,498 gallons, which is used by a population which was 592,063 in 1871, and was estimated in 1879 at 672,000, which is equal to 22·83 gallons per head for all purposes.

The supply is partly derived from Gravitation Works at Rivington, between Wigan and Blackburn, in the basins of the *RIBBLE* and the *DOUGLAS*, and partly from wells in the New Red Sandstone, within the watershed on which the city is built.

The Gravitation Works consist of 7 catchment reservoirs, covering 600 acres, or nearly a square mile, draining the springs off 10,000 acres of moorland. They have a united capacity of 4,059,000,000 gallons.

The following derive their supply from the *Liverpool Corporation Waterworks*:—Allerton, *acres*, 1586; population, 830; rateable value, 17,695*l*. Bootle-cum-Linacre, *acres*, 1580; population, 27,112; rateable value, 116,000*l*. Garston, *acres*, 1625; population, 10,131; rateable value, 54,963*l*. Great Crosby, *acres*, 1768; population, 5100; rateable value, 23,010*l*. Litherland, population, 2426; rateable value, 10,992*l*. Much Woolton, *acres*, 970; population, 4539; rateable value, 20,224*l*. Toxteth Park, population, 10,371; rateable value, 73,458*l*. Walton-on-the-Hill, population, 18,772; rateable value, 47,937*l*. (intermittent supply). Wavertree, *acres*, 1799; population, 11,157; rateable value, 75,034*l*. in 1877. Waterloo with Seaforth, *acres*, 740; population, 9107; rateable value, 51,581*l*.

A portion of the 20 square miles of area supplying the Liverpool private and Corporation wells is built over or covered with impermeable paving in the streets; and, further, only a portion of the eastern area is bare of Drift

Boulder Clay, which throws off the rainfall in surface floods, though a portion of the water is doubtless absorbed in passing through rock-cut valleys. The evaporation off this stiff clay-land, exposed as it is to the influence of the sun and air, is doubtless as high as 12 inches per annum, and the percolation probably not more than 5, though amounting probably to 10 inches in the area bare of drift.

Assuming 1 inch of rain to give 22,427 gallons per acre, or 14,353,280 gallons per square mile, which, spread over a year, gives a daily yield of about 40,000 gallons per square mile, the drainage area with 5 inches of percolation would give a daily volume of 4,000,000 of gallons off 20 square miles, while the yield from public wells alone is 6,250,000, proving the water in the subterranean supply is derived from an area outside the immediate surface drainage district, or else this water flows in from the river, along lines of faults, or that they act as direct ducts from other areas. In the public wells there is no evidence of percolation from the *MERSEY*. In the shallow wells near the Docks, where the natural head of water, derived from the land, is lowered, salt water from the river percolates to a certain distance inland, and fills up the void space. These wells are steadily deteriorating; but so long as the Corporation wells are not over-pumped this action will not affect them. The following table shows the average total quantity pumped from the four wells in 1876 somewhat exceeded that pumped in 1868.

AVERAGE DAILY QUANTITY OF WATER PUMPED FROM WELLS, 1868 TO 1876.

Year.	Green Lane.	Bootle.	Windsor.	Dudlow Lane.
1868	2,726,426	1,405,304	969,622	277,626
1869	2,661,314	1,490,745	844,912	328,568
1870	2,770,167	1,475,526	933,515	1,062,405
1871	2,828,032	1,399,049	864,000	1,247,403
1872	2,833,639	1,433,747	869,761	184,184
1873	2,779,059	1,469,253	827,655	810,590
1874	2,517,680	1,291,189	899,379	1,011,260
1875	2,533,050	1,399,791	821,182	1,103,307
1876	2,903,712	1,293,772	830,694	1,169,494

The following particulars of Wells in the New Red Sandstone belonging to the Liverpool Corporation, were furnished to the Underground Water Committee* of the British Association by Mr. G. F. Deacon, the Water Engineer of the Corporation, and by Dr. J. Campbell Brown, the City Analyst, in 1877:—

Bootle Well.—The depth of this well from the surface of the ground is 104 feet. The bottom of the well is 49 feet below Ordnance Datum. In connection with the well there are 15 boreholes, one of which (4 inches in diameter) is sunk to 571 feet below Ordnance Datum, one to 273 feet 5 inches below O.D., and one to 268 feet 5 inches below O.D. The other boreholes are shallow.

Constituents of Water expressed in parts per 100,000, *re-calculated from the Analyses quoted in R. Stephenson's Report of* 1850, *by Dr. Brown.*

No. 2, Bootle, No. 1 Lodgment. January 30, 1850.

Chlorine	2·777
Sodium	1·894
Magnesia	4·714
Lime	7·627
Sulphuric Acid	2·781
Silica	·686
Carbonic Acid	9·649
Organic matter, trace of potash, water of crystallization, and loss	4·014
	34·142
Hardness	25°·3

Dr. Brown states, that the water has undergone a great many variations in composition since 1850, and has now returned to almost the same composition as it had then. After the deep bores were sunk, the hardness was not much more than half as great as it was in 1850, owing to the fact that there are extensive alkali-waste deposits, which yield a large quantity of lime-salts to the water of the upper strata. By continual pumping since the existing bores were sunk,

* Mr. G. H. Morton, F.G.S., and Mr. Mellard Reade, C.E., F.G.S., represented the Committee in South Lancashire; the tabulated comparisons have chiefly been drawn up by the latter.

the hardness had gradually risen, until it is now slightly higher than it was in 1850. The deeper water is still less hard than the upper water. The following, he believes, are reasons for believing that no appreciable quantity of sea-water reaches the well:—If sea-water entered the well, one would expect more chloride of sodium and magnesium salts when the well is hard pumped, and when there is a less strong flow of underground water from the interior towards the sea, that is in dry weather. But

1. The proportion of chloride of sodium is almost exactly the same now as in 1850.

2. The proportion of chloride of sodium does not vary beyond very narrow limits, and is very nearly the same in Bootle well as in wells further inland, such as Dudlow Lane, Windsor, and Green Lane wells.

3. In October, 1875, when the hardness was reduced by the simultaneous stoppage of the pumping and fall of heavy rains, the proportion of magnesium salts was not altered, the change in the hardness having been due almost entirely to an alteration in the proportion of lime-salts.

Bootle Well.

	Hardness.	Level of Water below Ordnance Datum.
	°	ft. in.
On 5th Dec., 1868, Well	15	37 2½
On 8th Feb., 1870 „	18	38 4
On „ „ „ deep bore	16	—
On 26th June, 1872, well water	16½	38 0½
On 24th Sept., 1872 „ „	16½	37 3½
On 1st April, 1873 „ „	17½	37 4½
On 28th May, 1875 „ „	22·7	38 0
On 4th June, 1875, east side of well ..	22·4	40 4
On „ „ „ west „ ..	27·25	—
On 20th May „ deep bore	22	—
On 1st Sept., 1876 „	22·28	42 8

In 1876 the hardness varied from 22° to 24½°, and on 7th Dec., 1876, it was 25½°; the mean level was 34 ft. 7 in. below Ordnance Datum.

Dr. Brown does not find that there is any regular difference between the hardness in summer and winter.

Differences can be traced to heavy rainfall and the rate of pumping: *e.g.* the hardness of Bootle Well water was taken weekly for a year; it was generally about 23°, but after heavy rains it fell to 22° and 21°·8, and in very dry weather it rose to 24°. On 1st October, 1875, the hardness was 23°, and on 6th October, when the level of the water was 12 feet 6 inches above the bottom of the well, the pump was stopped for repairs. On the 8th October the water rose to 34 feet, and there was no unusual variation in the hardness; at that time heavy rains began to fall, and on 15th October, the level of the water being 48 feet, its hardness fell to 18°. The hardness due to magnesium salts was almost the same at this time as before the change, the difference being due to calcium salts. Pumping was then resumed on 15th October after the sample was taken, and in 7 days, viz. on 22nd October, the level was reduced to 17 feet, and the hardness rose again to 23°.

		°
On 31st January, 1877,	the water of well was	24·56
„ „	the average water of the deep bore ..	23·44
„ „	the water near the bottom of bore ..	20·56

Dudlow Lane Well.—Depth from surface of ground, 247 feet 3 inches. Bottom of well below Ordnance Datum, 49 feet. Borehole, 18″ diameter, sunk to a depth of 245 feet below Ordnance Datum.

The following is a tabulated statement of the levels of the water in the several wells in relation to the Ordnance Datum on the dates referred to by Dr. J. C. Brown in his report on the hardness of the water:—

	Hardness.	Level of Water below O.D.	
	°	ft.	in.
On 2nd Dec., 1868	6½	33	7
On 24th Sept., 1872	6	38	11
On 30th Sept., 1872	7½	7	0
On 20th Oct., 1873	7½	3	0 (above)

In 1874, when the pumps were frequently stopped, the average was 5¾°; the highest was 7°.

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 1st June, 1875, the deep bore was ..	7·86	34 9
„ „ „ well itself was ..	8	—
On 4th Sept., 1876, the deep bore was ..	8·88	40 6
„ „ „ well was	8	—
The average in 1877 was	7½	—

The hardness was taken weekly in 1874, and there was no regular difference between the hardness in summer and winter.

Dudlow Lane.—Finished sinking well, 1868. In 1870 a borehole, 18″ diameter, sunk to 196 feet below bottom of well. Pumping stopped during most of year 1872 and part of 1873.

The Green Lane, Bootle, and Dudlow Lane boreholes are provided with plugs, which are occasionally raised or lowered to regulate the depth of water in the wells, according to the speed at which the engines are worked.

Green Lane Well.—The depth of this well from the surface of the ground is 185 feet. The bottom of the well is 49 feet below Ordnance Datum. There are two boreholes; one, of 9″ diameter at the top, and 6″ diameter at the bottom, is sunk to a depth of 248 feet 6 inches below O.D.; the other, of 18″ diameter, is sunk to a depth of 359 feet below O.D.

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 2nd Dec., 1868, the well was	13	38 4
On 26th June, 1872, the deep bore was ..	14½	36 1½
On 28th March, 1873, the well was	13½	35 0
On 25th May, 1875, the deep bore was ..	16	38 6
„ „ the well was	14½	—

In 1875 the percolating water from the upper strata at 40 feet above the bottom of the well was 10°, while the mixed water of the well taken at the same time was from 16° to 16½°.

	°
On 5th Sept., 1876, the water of the deep bore was ..	18·28
„ „ „ „ well itself „ ..	18

In 1876 the average was from 18° to 19½°.
In 1877, Jan. „ „ „ 20°·6.

In 1868 a new well, 12 feet × 9 feet, was sunk 185 feet. In 1869 a borehole, 18″ diameter, sunk in new well to 310 feet below bottom. Engine power not increased.

The following analysis has been re-calculated by Dr. Campbell Brown, in parts per 100,000 :—

No. 11, Green-Lane Well, 50 feet from bottom of well. January 30, 1850.

Chlorine	2·306
Sodium (in combination with chlorine)	1·495
Soda (as sodium sulphate)	1·391
Magnesia	0·000
Lime	4·209
Sulphuric Acid	1·795
Silica	·914
Carbonic Acid	3·302
Organic matter and loss	4·015
	19·427
Hardness	7°·5

The proportion of mineral salts, and especially of the hardening salts, carbonate of lime and sulphate of magnesia, has increased very much since 1850, and is still increasing as the well is pumped to a lower level. The deep water is rather harder than the upper water.

Windsor Well.—Depth from surface of ground, 210 feet. Bottom of well below Ordnance Datum, 24 feet 2 inches. There is one borehole of 6 inches diameter at the top, and 4 inches diameter at the bottom. The total depth of the borehole is 269 feet below O.D.

	Hardness.	Level of Water below O.D. ft.	in.
	°		
On 5th Dec., 1868, the well was	15	19	1½
On 26th June, 1872 „	18	17	1
On 30th Sept., 1872 „	17	16	6½
On 20th Oct., 1873 „	16½	—	
On 24th May, 1875 „	19¾	17	9
„ „ „ the deep bore was	19	—	
On 13th March, 1876, the well was	21½	17	11
On 8th June and Sept. 8th „	23½	20	0
On 7th Dec., 1876, the well was	24½	20	0
On 1st Sept., the deep bore was	21·16	—	

Analysis re-calculated by Dr. Campbell Brown, in parts per 100,000 :—

No. 6, Windsor Well, 2 feet from the bottom lodgment. January 29, 1850.

Chlorine	2·964
Sodium	1·921
Magnesia	5·055
Lime	7·250
Sulphuric Acid	·414
Silica	1·714
Carbonic Acid	11·185
Organic matter, traces of potash, water of crystallization, and loss	2·829
	33·332
Hardness	25°·6

This water has undergone several changes, having deteriorated as the population around it increased; but since the sewering of the district and the paving of the streets were completed it has very much improved, and the composition is now almost the same as it was in 1850. The hardness appears to be less now than it was then; but this may be due to a difference in the test-solution employed, as two experimenters seldom get precisely the same figures for hardness. The same standard soap-solution has been used for several years, and the hardness is found to be slowly increasing. It is less in the deep water than in the upper water.

Rainfall at Sandfield Park, West Derby.—*Observer*, Mr. Biggs.

Rain-Gauge, height above Ground 1 ft. 2 in., above Mean Sea-level 147 ft.

	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.
January ..	1·94	3·20	1·94	1·90	2·84	2·00	·20	4·30	1·00	2·42
February ..	2·10	2·90	1·18	1·84	·70	·56	·80	2·70	1·20	1·00
March ..	·80	1·70	1·08	2·80	1·54	·75	·20	2·80	1·50	1·40
April ..	·76	1·10	3·26	1·64	2·90	1·50	1·30	2·75	·40	·92
May	3·50	1·46	1·36	·95	4·90	·90	1·10	1·50	1·20	1·80
June	·70	3·90	·95	·42	1·30	1·40	2·80	6·20	1·70	·56
July	3·10	2·51	4·80	·46	1·00	·80	3·70	7·00	3·20	3·50
August ..	4·40	3·80	1·64	3·62	2·50	2·00	1·30	2·30	3·10	3·75
September	·63	5·50	2 14	2·14	6·54	2·30	4·70	6·30	2·70	2·60
October ..	3·00	2·10	4·10	4·42	2·94	6·00	5·90	6·42	3·84	3·90
November	2·50	4·50	1·92	2·28	3·70	3·30	1·75	2·94	2·00	5·00
December ..	1·00	2·23	3·05	6·56	2·16	2·70	2·00	4·36	·80	1·60
Totals ..	24·43	34·90	27·42	29·03	35·02	24·21	25·75	49·57	22·64	28·45

RIVER ALT (XLVII., in part).

Length, 14 miles; area, according to the Catchment Basin map of the Ordnance Survey, 126 square miles, of which 33 are drained by streams flowing directly into the *MERSEY* estuary at Liverpool. Of the remaining 93 square miles, 7 consist of the Coal Measures, brought to the surface by the Croxteth fault, and the remainder of New Red Sandstones, ranging from the Pebble beds to the Waterstones, which I observed in 1868, in the railway cutting at Orrell, near Litherland. In the higher parts of the ground at Aintree, Little Crosby, and Maghull the rock is more or less overlaid by Upper Boulder Clay. At Sefton the alluvial plain of the river opens out to a wide extent, and forms the level stretch so well known to the lovers of coursing. At the base of the alluvium occurs a bed of peat resting on a greyish-blue silt, which can be traced to the estuary of the river at Hightown, appearing on the beach beneath the Sand Dunes. At the base of the peat occurs a large number of trunks of trees, the roots of some of them being imbedded in the clay beneath. This submarine forest was first described in the 'Gentleman's Magazine' in the last century.

To the north of the *ALT* alluvium is an extensive tract of peat moss, an area of former obstructed and present artificial drainage. The southern portion is drained into the *ALT*, on which are windmills and steam-engines lifting the water to the sea, under the Alt Commissioners Act. The northern mosses are drained into the Crossens Basin, where also are steam-engines lifting the water from Martin Mere, once one of the largest lakes in Lancashire, though never of great depth.

The watershed forming the eastern margin of this basin, separating it from the district drained by *Rainford* Brook, traverses a succession of peat mosses resting on beds of Glacial Drift; in one of them rises *Simonswood* Brook, draining the valley east of Melling and Kirkby, at both of which places the Pebble beds* crop to the surface. In another moss

* The St. Helen's Corporation Waterworks propose to apply for powers to sink two wells in these rocks.

further north rises *Bickerstaffe* Brook, which receives *Knoll* Brook, and drains the valley between Maghull and Town Green, passing the pumping stations at Springfield, near Town Green, of the *Southport Waterworks Company*. There are two shafts here, and a heading at 135 feet from the surface. The total depth is 232 feet; the pumping-level of the water is 125 feet from the surface, and the rest-level is at the surface; 500,000 gallons can be pumped without further lowering. The section consists of 79 feet of Glacial Drift (Sand and Clay), and 153 feet of soft Sandstone of the Upper Mottled Bunter in the well, and a further 20 feet in a boring.

CROSSENS BASIN (XLIV.).

This basin has an area of 55 square miles, all of which are on the Trias, with Sandstones on the eastern margin and Keuper Marls in the western area. These are seen in a few brook sections at Brown Edge and Scarisbrick, but elsewhere are deeply overlaid by Glacial and post-Glacial Drift deposits. In a well at Scarisbrick Park the Marls were penetrated, and beds of Chert, Limestone, and Grit found beneath, which point to the Marls overlapping the Triassic sandstones, as at Charnwood Forest. If this be so, the rocks found were probably referable to the Yoredale rocks. Further on the sea-margin, at Birkdale Park, a boring was carried to a depth of 186 yards without finding the base of the Keuper Marls. At Halsall and Cleve Hill Keuper Sandstone crops to the surface in a range of hills rising from the peat-moss plain, more or less covered with Upper Boulder Clay, and flanked at the base at Shirdley Hill and elsewhere by sands of post-Glacial age, which I have named "Shirdley Hill Sand." They constitute a range of ancient, but post-Glacial Sand Dunes, from which much sand has blown over the interior of the country, and were blown from the sandy shore, which is preserved in the beds underlying the eastern margin of the peat-moss.

The *Southport Waterworks Company* have three wells in this basin, one at Scarisbrick in the hard upper beds

of the Upper Mottled Sandstone, 124 feet deep, with no borehole; the water rises to the surface and drains away into an adjacent quarry. It is not used or pumped. North of Aughton, west of Ormskirk, are two wells known as the Pilot shaft and the Parliament shaft, 180 feet in depth, with boreholes to 222 feet from the surface. At 144 feet from the surface are two adit levels; the water is only pumped down to 110 feet from the surface, with two engines. The Glacial Drift is only 40½ feet thick, and contains numerous shells of mollusca; the remainder is in soft Red Sandstone of the Upper Bunter.

Southport.—*Acres*, 3,665; population, 32,191; rateable value, 188,007*l.* Is in district of supply of *Southport Waterworks Company*, who deliver 600,000 to 1,000,000 gallons to this Urban Sanitary Authority from a reservoir 9 miles distant, filled by pumping wells in the New Red Sandstone; Works under Southport Waterworks Acts, 1854, 1856, 1867, 1870, and 1878.

Birkdale Park.—*Acres*, 2214; population, 8706; rateable value, 43,797*l.*; supplied by *Southport Waterworks Company*.

Ormskirk.—*Acres*, 573; population, 6651; rateable value, 14,711*l.*; supply, 250,000 gallons, from well in the Upper Mottled Sandstone, constant during the day. The well is 129 feet above Ordnance Datum, is 60 feet deep, and 7 feet diameter; there is no borehole. Before pumping the water stands at the surface, after pumping it is reduced to 2 feet from the bottom of the well, or 71 feet above Ordnance Datum; its level is restored by two hours' rest, and is affected by rain within 24 hours. It contains 6·68 grains of salts (chiefly common salt) to the gallon.

RIVER DOUGLAS (XLVI.).

Length, 21 miles; area, 168 square miles, according to the Catchment Basin Map of the Ordnance Survey, but this requires some modification. In it is included 12 square miles of Coal Measures, drained by the *Croal*, a tributary

of the *Irwell*, and therefore belonging to the *MERSEY* Basin. On the other hand, the remarkable valley lying at the foot of Anglezark Moors, in which are constructed the reservoirs of the *Liverpool Corporation Waterworks*, occupying 16 square miles of Millstone Grit and Lower Coal Measures, is represented as belonging to the basin of the *RIBBLE*, instead of which it was formerly drained by the *DOUGLAS*, which is impounded in it, as well as water brought from the *Roddlesworth* in an aqueduct crossing the watershed, crossing the *Col*, between the basins of the *RIBBLE* and the *DOUGLAS*. These alterations give an additional 4 miles of area to the *DOUGLAS*, bringing it up to 172 square miles, of which 130 consist of Millstone Grit and Coal Measures, 1 of Permian, and 41 of Trias.

Between the margin of the peat-moss formerly covered by Martin Mere and the *DOUGLAS* between Rufford and Hesketh Bank, a tract of Upper Boulder Clay intervenes, the top of which forms the *DOUGLAS* watershed, running from Hesketh Bank by Tarleton and Sollom to Rufford. From this point, Burscough Junction, the watershed traverses a peat-moss, the surface of which is at or about high-water mark, and were the peat removed the *DOUGLAS* would flow over Martin Mere to Crossens, instead of through the valley between Tarleton and Bretherton. The formation of the estuarine deposits at Crossens probably caused the obstruction of drainage, which led to the growth of peat and the formation of Martin Mere. The waters of the *DOUGLAS*, thus deflected northwards from their previous persistent north-west direction by Wigan, Parbold, Horscar, and Crossens, flowed over the three miles of low ground intervening between Horscar and Sollom, joined the waters of the *Yarrow*, and fell into the *RIBBLE*, through the valley cut in the Boulder Clay by the *Yarrow* and its tributary the *Lostock*. The rainfall at Rufford, 38 feet above the sea, was in—

1876.	1877.	1878.	1879.	1880.
36·57	49·68	34·63	32·82	35·14

Average rainfall for the last 10 years, 37·18 inches.

Following the watershed of the *DOUGLAS*, it runs along the Upper Boulder ridge, on which is situated the village of Burscough, to near Ormskirk, where it trends south-east and ascends Scarf Hill, formed by an outlier of Keuper Sandstone, thrown in by a north-north-west fault, and attaining a height of 250 feet, the underground water-level here being 100 feet below the surface. East of this point it crosses the great boundary fault of the Coal Measures, with a throw equal to the thickness of the whole of the Sandstones of the Trias, but no trace is left on the ground. The whole has been planed perfectly flat, and the Glacial Drift overlies alike Trias and Coal Measures; the fault is not even visible.

The watershed gradually rises to 272 feet near the source of the *Tawd* to Billinge Beacon, from which it descends to 102 feet at Bryn Moss, at the point indicated as the probable pre-Glacial course of the *Plank Lane* stream (and possibly of the *Irwell*) into the valley of the *DOUGLAS*. From Bryn Moss it rises to 155 feet at Amberswood Common, and ascends, by Aspull Moor, to 500 feet between Haigh and Blackrod, from which it descends into the Col Valley at Horwich, to 367 feet at Red Moss, thence ascending to 1150 feet at Horwich Moor to its culminating point at 1450 feet on Winter Hill.

Following the left bank of the *DOUGLAS*, the first important tributary is *Eller* Brook, rising on the northern slope of the Scarf Hill ridge, and draining Burscough, and the western slope of Lathom Park, which lies on the upper beds of the Gannister series. A short distance south of the infall of this stream is that of *Whain* Brook, draining Horscar Moss.

River Tawd.

At Wanes Blades Bridge is the infall of the River *Tawd*, rising near Pimbo Lane Station, draining the Lower Mottled Sandstone inlier of Digmoor Green, the Middle Coal Measures of Skelmersdale, and the Gannister beds of the east side of Lathom Park.

LATHOM.—*Acres*, 8694; population, 4161; rateable value, 31,137*l.* 7*s.*; wells.

SKELMERSDALE.—*Acres*, 1941; population, 5707; constant supply of 700 gallons from Ormskirk Local Board of Health, brought by tank waggon—brought daily by rail to Skelmersdale, and contents sold to inhabitants; supply supplemented by wells and ditches.

The eastern margin of the *Tawd* drainage area is the Ashurst Beacon ridge, which, once continuous with that of Harrock Edge, was cut through in pre-Glacial times. The valley afterwards was filled in with Glacial deposits, and since to some extent re-excavated. Terraces of Upper Boulder Clay, Middle Sand, and Lower Boulder Clay flank the hill-side, through Dalton, Waltham Green, and Upholland, where they are cut through by the gorge of *Dean* Brook, Orrell, Lamberhead Green, and Pemberton.

ORRELL.—Population, 4299; rateable value, 10,000*l.*; supply from Pemberton Local Board preparing.

PEMBERTON.—*Acres*, 2894*l.*; population, 13,763; rateable value (district), 37,000*l.* Waterworks scheme was sanctioned by Pemberton Local Board Water Act, 1875, to supply 15 gallons per head, from a reservoir to hold 21,000,000 gallons, of surface-water flowing off cultivated land. The reservoir was made on porous strata, overlying old coal workings. In opposing the Bill, I stated it would not be made watertight, which has proved to be the case. After exhausting their borrowing powers the Board has had again to seek assistance from the Local Government Board.

UPHOLLAND.—*Acres*, 4685; population, 4435; rateable value, 21,268*l.*; wells and springs.

The last feeder of importance is that draining Bryn Moss and Worsley Mains, flowing north along the line taken by the Leigh and Hindley Canal, excavated entirely on Glacial Drift.

A little south of Wigan the river *DOUGLAS*, following it up stream, turns eastward and northward; flowing through a gorge in the Glacial Drift, at the curve it receives *Clarendon*

Brook, rising above Kirkless Hall, the site of the large iron-works of the Wigan Coal and Iron Company.

Ince-in-Makerfield.—*Acres*, 2320; population, 16,017; rateable value, 52,715*l.*; constant supply of 143,000 gallons from two wells, 150 feet in Pebble Beds at Golborne, 5 miles distant; service reservoir constructing, water softened by Clark's process; Ince Water Act, 1872. In 1871 the *South Lancashire Water Company* promoted a Bill in Parliament for the supply of Ince, West Houghton, Aspull, Blackrod, Haigh, Adlington, Horwich, Lostock, portions of Halliwell, Heaton, Leigh, and Hindley. Ince opposed, having their Golborne Bill pending. Hindley opposed, wanting to be supplied in bulk, and both townships were left out of the Bill. On Ince refusing to supply Hindley, the latter obtained powers in their Gas Act of 1872 to obtain water from the Red Sandstone at Lowton, but the works were not carried out, and the Board united with Hindley in 1876 to obtain an Act to acquire the lapsing powers of the *South Lancashire Waterworks Company*, and, whilst the works are being carried out, to obtain water from Bolton Corporation, at 6*d.* per 1000 gallons, for 7 years from 1876.

Aspull.—*Acres*, 1905; population, 8111; rateable value, 27,901*l.* 13*s.*; scheme of supply now before Local Government Board.

The gorge of the *DOUGLAS* at Wigan cuts the town into two parts, that on the left bank being called Hardybutts. Good sections of the Middle Drift are seen in sand-pits, at the back of the main street. The sand is generally current-bedded to the south-south-east, and contains fragments of marine shells. A little below the level at which the Leeds and Liverpool Canal contours the district, the sands are overlaid by Upper Boulder Clay, and both thinning out, the Coal Measures come to the surface, which continue by Haigh Hall and Fir-Tree House, at an elevation of about 500 feet. Above this, both on the watershed, and on the other side of it, at Aspull Moor, a cold clay comes in, probably of Upper

Glacial age. Near Worthington Hall, north-east of Standish Railway Station, the *DOUGLAS* commences to describe another curve of the "S" to which its course may be compared, trending north-east with the strike of the Middle Coal Measures over which it flows, the north-north-east strikes from Wigan to Worthington being changed by the action of the Haigh fault to north-east. Other faults again change the strike, between Huyton Bleach Works, near Adlington and Blackrod, to south-east, and the direction of the *DOUGLAS* changes with it, and continues to the Blackrod fault, east of which its present course is governed by the occurrence of Drift, Glacial and post-Glacial. East of the fault, which is a downthrow west, the strike-direction of the stream is maintained by a feeder draining the *DOUGLAS* basin side of Red Moss, but the *DOUGLAS* trends from the north-east by Anderton Hall, and before the formation of the Rivington reservoirs turned at right angles, and flowed again from the north-west for the third time.

Mr. Robert Stephenson, in his report on Liverpool water supply in 1850, stated "that a uniform supply of 12,000,000 or 13,000,000 gallons per day may, in my judgment, be reckoned on with absolute certainty." The average rainfall was originally taken at 48 inches, of which 36 inches was assumed to be available, and one-third of this, or 12 inches, was allowed for millowners' compensations, leaving 24 inches for Liverpool. The actual rainfall (average of 17 years) was only 45·71 inches, and the average 11 years delivery to Liverpool only 14½ inches, and in 1865 only 9¾ inches, instead of the 24 inches depth originally anticipated. With an additional storage reservoir then constructing, holding 1,200,000,000 gallons of water, a total storage of 68,500 cubic feet to the acre was afforded, which in a run of dry years had little chance of being filled, and which the engineers only calculate to yield 10,500,000 gallons a day in average years, and 9,000,000 gallons in cycles of three dry years. This quantity in 1861 was supplemented by 7,500,000 gallons per day from wells at Liverpool. The gravitation

works have never supplied more than 17,000,000 gallons per day, after deducting 8,300,000 gallons per day compensation to mills; in 1864–65–66, the average supplied to Liverpool was less than 8,000,000 gallons, in 1865 only 6,177,000 gallons per day. In September, 1867, the compensation water was reduced to 6,500,000 gallons a day, by the purchase of 1,850,000 gallons, which was available in the 1868 drought. The full store of water at Rivington was reduced by the drought from 3100 million gallons to 700 million gallons, or (including compensation) to 50 days' supply of seven hours' service.

YIELD of the RIVINGTON RESERVOIR, derived from information afforded by THOMAS DUNCAN, Esq., OCTOBER, 1865.

YEARS.	Rainfall by Daily Gauge.	Quantity Collected.	Equal to Proportion of Rainfall.		Given to Compensation to Mills per Day.	Delivered in Liverpool.
		Gallons per day.	Per Cent.	Inches.		
1861	46·38	22,173,493	77·13	=35·77	8,300,000	10,403,818
1862	48·51	24,844,597	82·63	=40·08	8,300,000	10,790,414
1863	51·01	25,243,003	79·84	=40·72	8,300,000	11,195,044
1864	39·035	17,125,406	71·37	=27·85	8,300,000	11,046,339
Mean	46·233	22,346,624	77·74	=36·10	8,300,000	10,841,403

LIVERPOOL WATERWORKS DISTRICT.

Minimum rainfall of 14 years .. .. .. 34·78
Mean „ „ .. .. .. 45·14
Min. 77 per cent. of Mean.

Year.	Rainfall.	Collected.
1861	46⅓	35¾
1862	48½	40
1863	51	40¾
1864	39	28

Mr. T. Duncan* stated that the *Rivington Waterworks* were based on the calculations of Mr. Hawksley; that the daily yield would be 16,000,000 gallons a day. Mr. Hawksley assumed a mean rainfall of 48 inches, and allowed 25 per cent. for absorption and evaporation, and a third off this quantity for compensation in bulk, the resultant available has fallen far below the quantity expected.

The right bank of the *DOUGLAS*, below the reservoir, drains the district of Anderton, the south side of Adlington, Worthington, and Standish. At the latter place the Coal Measures crop to the surface, but generally they are deeply overlaid by Upper Boulder overlying Middle Sands, the latter cropping in the valley of the *DOUGLAS* and its deeper tributary valleys drained by small streams; these have short courses, a minor watershed running parallel to the river through Standish and Wigan Lane to Wigan, which is built on Glacial Sand or Middle Drift, resting on Coal Measures, from which the coal has been largely worked, causing a certain amount of subsidence.

Blackrod.—Population, 4234; rateable value, 21,360*l.*; Waterworks constructing, under Blackrod Local Board Act, 1876, impounding springs at Wilder's Wood, in the township of Horwich.

Adlington.—Population, 3258; rateable value, 8390*l.*; no public water supply; insufficient supply from wells and lodges.

Standish with Langtree.—*Acres*, 3698; population, 4261; rateable value, 19,747*l.*; no public supply.

Wigan.—*Acres*, 2188; population, 48,196; rateable value, 128,000; constant supply under Wigan Waterworks Act, 1853, of 1,800,000 gallons, including compensation water from gravitation works storing surface waters; the water is filtered at the storage reservoir, and then pumped into the high-service reservoir.

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* 'Royal Rivers Commission,' p. 120.

Rainfall at Wigan Waterworks, 225 feet above the sea, taken by Mr. W. Bolton.

1858	36·18	1862	49·01	1866	43·61	1870	34·35	1874	41·26	1878	38·66
1859	37·35	1863	44·70	1867	33·51	1871	36·53	1875	37·70	1879	35·36
1860	46·04	1864	34·79	1868	37·58	1872	54·84	1876	40·37	1880	36·98
1861	47·63	1865	33·48	1869	40·52	1873	34·28	1877	51·10	1881	..

Average of the 21 years, 1858–1878 inclusive, 40·64 inches; average of the three wettest years of that period 50·49, or 9·85 above the average; average of the three driest years, 33·78 inches, or 6·86 inches below the average. 1858–59, 1864–65, 1870–71, were examples of dry years following each other; 1860, 1861, 1862, of three wet years following each other. In 1858 rain only fell on 117 days.

Between Wigan and Shevington the only important feeder falling into the right bank of the *DOUGLAS* is *Wrightington* Brook, impounded in Wrightington Park, and draining entirely Drift-covered Coal Measures. Another feeder comes in east of Parbold Hill, which drains a curious valley running east and west, parallel to the watershed, between Adlington and Harrock Hill. The sides of the valley are the sands of the Middle Drift, and at the bottom rises the *Hic-bibi* Brook. At Bispham a fault brings in the New Red Sandstone with a small exposure running east and west, parallel and close to the exposure on the upthrow side of Permian Marls with a thin band of Magnesian Limestone, described by Professor Hull, resting on the Lower Coal Measures uncomformably. Further north, at Black Moor, a feeder draining the soft Red Sandstone of Maudsley comes in, and between Hanging and Red Bridges it receives an important tributary, the River *Yarrow*.

River Yarrow.

This stream is 15 miles in length, rising near the source of the *DOUGLAS;* its drainage area forms the northern part of that basin. Following its left bank, up stream, it traverses

the New Red Sandstone by Croston and Eccleston, and crosses the fault bringing in the Lancashire Coalfield, which is well seen in *Lyd* Brook at Eccleston Green, where Pebble-bearing Sandstone is thrown against Lower Coal Measures at about 125 feet above the mean sea-level. The stream flows past Gillibrand Hall, where it trends south through a deep valley in the Glacial Drift to Duxbury Park, where it turns north-eastward with the strike of the Middle Coal Measures, over which it flows, and which forms the floor of the Drift-cut valley; crossing the Chorley fault, the stream trends eastward to its source above the Rivington reservoir, which intercepts its upper waters. The village of Rivington, on the eastern bank of the reservoir, is in the part of the basin thus intercepted.

Croston.—*Acres*, 2361; population, 1791; rateable value, 9143*l.*; private wells.

Following the right bank of the *Yarrow*, down stream, after leaving the Rivington reservoirs, an important feeder comes in, known as *Black* Brook, rising at Green Hill, 1170 feet above the sea, and flows through the valley of Kinderscout Grit, separating Anglezark from Wheelton Moors, to the Liverpool Water Supply Conduit, thence, crossing the fault throwing in the Newer Millstone Grits and Lower Coal Measures, it flows past Heapey Print Works, and through a deep valley between Grey Heights and Chorley, and falls into the *Yarrow* at the northern end of Duxbury Park. From the infall of this stream to Euxton, the Drift-covered country around Chorley, rising to 313 feet at Hastwood Green, and 364 feet on the watershed, is drained by streams which do not expose the rock surface, and are chiefly cut through the sands of the Middle Drift.

Chorley.—*Acres*, 3613; population, 19,472; rateable value, 55,000*l.*; supplied, under Chorley Waterworks Act, with a constant daily quantity of 400,000 to 500,000 gallons, including trade supply, from reservoir storing springs and streams on the Anglezark Moor. The reservoir is on the eastern margin of the upper Rivington reservoir. The top

water is about 520 feet above the mean sea-level. The reservoir is constructed on shales underlying the Second Grit, and is embanked at both ends; the bye-wash is at the northern end, and the waste water flows into the reservoir.

Northward, the watershed limit of the *Lostock* tributary to the *Yarrow* trends north-north-west over the tops of the Millstone Grit of the Anglezark Moors, descending to 1215 feet at Bromley Pastures, 1028 at Withnell Moor, and to 555 in the Withnell Col Valley, between the valleys of the *DOUGLAS* and *MERSEY*. Thence, ascending Withnell Hill, it attains 675 feet near the Church on the Millstone Grit Rough Rock. Leaving this formation, it crosses a synclinal, bringing in Lower Coal Measures, traversed by the Leeds and Liverpool Canal, which is crossed at 360 feet. On the opposite side of this synclinal is the long escarpment formed by the Rough Rock of Brindle and Hoghton Towers, traversed for a short distance by the watershed at an elevation of 425 feet.

A north-west fault at Brindle brings in the Shales under the Rough Rock, which are traversed by the watershed to Thorpe Green, after which it crosses the third Millstone Grit and underlying Shales, and the termination and summit-level of the branch canal, carried from the Leeds and Liverpool Canal at Heapey. This branch canal was formerly connected by a tramroad, laid on stone sleepers, with the Lancaster Canal at Preston, crossing the *RIBBLE* by a wooden bridge still standing, and the alluvial flat of that river by a long embankment now utilized as a public promenade.

The Walton-le Dale water supply is now derived from a well sunk to a depth of 500 feet in the Millstone (*third*) Grit, at a point near the summit station, 320 feet above the sea, chosen by myself. Between the Walton Summit Station and Bamber Bridge, the fault throwing in the New Red Sandstone is crossed by the watershed, which descends to 150 feet at Bamber Bridge; the rock is deeply covered with Glacial Drift, and is probably not less than 125 feet below the surface. Westward the watershed runs nearly parallel to the *Lostock*,

descending to 114 feet at Farrington, where it passes on to the extensive tract of peat moss, forming Longton, Farrington, and Hoole Mosses, which rest on the Upper Boulder Clay, thence passing west to the mouth of the *DOUGLAS*, at Marsh Houses.

River Lostock.

West of Croston the *Yarrow* receives this stream; it is 13 miles in length, rising on the western slope of the Rough Rock of Withnell, which rises to 675 feet above the sea. It follows the strike of the Lower Coal Measures, between Heapey and Brindle, to Whittle-le-Woods, where it flanks the Millstone Grits of Brindle and Clayton Green, crossing the fault bringing in the Trias at Cuerden Park, it describes an S-like curve, and flows by Bamber Bridge, Farrington, Ulnes-Walton, and Bretherton. Feeders on the left bank drain the district of Leyland. A feeder on the right bank drains the valley between Hough Moor and the Clayton Green ridge. At the head of the valley is the boring for the water supply of Walton-le-Dale.

Rainfall at Crooke Hall, Whittle-le-Woods, 265 feet above the sea (Mr. T. J. Hare) :—

1876.	1877.	1878.	1879.	1880.
38·43	53·64	36·96	36·48	36·73

Giving an average for the 5 years of 40·44 inches.

Leyland.—*Acres*, 3741; population, 4161; rateable value, 22,800*l.*; at present supplied by wells in the sands of the Middle Drift; a pumping scheme is in preparation, from a well and boring.

The *DOUGLAS*, from the infall of the *Yarrow*, flows through a low tract of country, covered with Glacial Drift, which has been cut into by streams, as *Bretherton Carr* and *Much Hoole* Brooks. There is no natural division north of the *DOUGLAS* watershed at Marsh Lane, further than these small streams drain in the one case into the tidal *DOUGLAS*, and in the other into the estuary of the *RIBBLE*.

CHAPTER XXXII.

THE RIBBLE AND WYRE BASINS.

CATCHMENT BASIN XLV.

Area, 7 square miles, drained by a brook rising on the peat moss at White Stakes, west of Farrington, and flowing through the depression in the Boulder Clay between Longton and Hutton into the *RIBBLE* estuary, of which basin it practically forms a part.

RIVER RIBBLE (XLII.).

Length, 54 miles; area, given by the Ordnance Survey Catchment Basin Map, 585 square miles, which has to be reduced by the 16 square miles belonging to the *DOUGLAS*, bringing the area to 569 square miles, of which 484 square miles consist of Carboniferous rocks, 2 of Permian, and 83 of Trias. Its southern watershed traverses Hutton, Farrington, and Bamber Bridge, where it attains an elevation of 150 feet; thence it ascends to Walton summit-level, 340 feet, and runs along the strike of the Rough Rock, rising to 425 feet on Duxon Hill, crosses the Fenniscowles synclinal of Lower Coal Measures, ascends to 675 feet at the Rough Rock of Withnell, and descends to 555 feet at the Withnell Col Valley; thence it ascends and traverses Anglezark Moors to 1215 at Bromley Pastures, where it trends east, and descends to Longworth and Roddlesworth Col Valley, which it crosses at 968 feet. Ascending the opposite hill across the strike of the Millstone Grit, it crosses the Gannister Coal synclinal at the top of Darwen Moor, 1319 feet above the sea; thence it trends eastwards, over hill-tops, most of which are capped by peat, forming Cranbury, Anshaw, Orrell, Hoddesden, and

Egerton Mosses; the latter is in the col valley at the head of *Broadwood* Brook, flowing into the Belmont reservoir. Leaving the moss, the watershed ascends Pike Low, and traverses the Lower Coal Measure synclinal, ranging through Haslingden, Oswaldtwistle, and Haslingden Moors above Haslingden. Crossing the col valley between the latter and Baxenden, it reaches Cribden Moor, where it turns at right angles, and trends north to Hambledon Hill. Here, east and west trough faults let in a belt of the Arley Mine of the Middle Coal Measures; the faults themselves are lead-bearing.

To the east of this watershed are the head waters of the *Irwell*, to the west and north those of feeders of the *Calder*. From Hambledon the *RIBBLE* and *Irwell* watershed trends east by the ridge of Hapton Park, which direction is continued until it terminates against the Central Pennine watershed, the northerly range of which has been described in treating of the head waters of the west central Yorkshire rivers. The *RIBBLE* Basin portion of the Pennine watershed, measured in a direct line from Todmorden, is 38 miles, while at Preston the north and south watersheds are only 5 miles apart. Northwards from the former place, the watershed passes east of Colne, by Barnoldswick, Long Preston, Horton-in-Ribblesdale, to a point between Hawes and Whernside, near sources of the *LUNE* and the *AIRE*.

The watershed of the right bank of the Upper *RIBBLE* runs parallel to the stream, and the left bank watershed as far as Giggleswick, the valley of Ribblesdale being only 3 miles in width. From Giggleswick the watershed trends west, the basin widening out, being drained by the tributary, the *Hodder*, the western limit of which is the county boundary between Yorkshire and Lancashire, running along the crest of the Bleasdale Fells. At Parlick Pike the watershed leaves the county boundary and crosses the col between the *Hodder* and *WYRE* basins, ascends the southern end of Longridge Fells, and then turning at right angles descends to the Drift plain, which it traverses to the sea between Blackpool and Southshore.

Following the left bank of the *RIBBLE*, up stream, from the estuary at Hutton, it flows through a valley entirely cut in Glacial Drift, consisting of the Upper Boulder Clay, Middle Sand, and Lower Boulder Clay, reaching a thickness of nearly 200 feet, and resting on a surface of the Pebble Beds of the New Red Sandstone, a little below high-water mark at Preston, sloping seawards, and rising to 50 feet above the mean sea-level at Samlesbury. The valley has an average width of three-quarters of a mile, an alluvial plain occupying the bottom, and occasionally older alluvial terraces the sides. Near the bottom of the alluvium of the lowest plain is a deposit of peat with fragments of roots and branches of trees, which may be traced to be a continuation of the thick deposits of peat fringing the western coast, which therefore grew after the valley of the *RIBBLE* had been excavated as deep as at present.

River Darwen.

The southern watershed is only 2 miles distant from the river between Penwortham and Walton-le-Dale. The tract of Drift country to the south is drained by small streams, which have not cut the valleys down to the rock. Opposite Frenchwood Park the *RIBBLE* changes its direction, and trends north-east, and receives the *Darwen*, draining a large area of Millstone Grits and Coal Measures, and about 3 square miles of Pebble Beds, and about a square mile of Permian Sandstone at Roach Bridge, where the Permian rests on various denuded Carboniferous rocks, and is cut off to the west by the fault bringing in the New Red Sandstone.

Following the left bank of the *Darwen*, up stream, it trends from the south-south-east, flowing over various Millstone Grits, and cuts a gorge through the Rough Rock at Hoghton Towers, which reach a height of 575 feet, and flows over Lower Coal Measures to Fenniscowles, where it turns at right angles and flows in the direction of the strike, the former direction being that of its tributary the *Roddlesworth*, which it receives at an elevation of 250 feet. The

feeders of this stream rise at the Belmont Col at 968 feet, and at Calf Heybrook at 1170 feet. From their source to the Roddlesworth reservoir of the *Liverpool Waterworks*, all the water is intercepted, except in excessive floods. The flood water, and the drainage of the lower part of the valley around Tockholes, is intercepted by the reservoir of the Star Paper Mills. Their supply is supplemented by a boring, which I recommended to be sunk, close to the works, to the Rough Rock, from which the water, absorbed at higher levels to the south, rises to the surface. The water, supported by the Shales beneath the Rough Rock, is intercepted by the boring in its path to the Fenniscowles synclinal.

From Fenniscowles to Witton the *Darwen* flows along the strike of the Lower Coal Measures, turning at right angles at Witton, and flows parallel to the Over Darwen fault west of the stream, to its source at Cranbury Moss. The fault throws up the Millstone Grit to the west, which is traversed by numerous tributary feeders. The banks of the *Darwen* drain entirely a Lower Coal Measure area, flowing past Over Darwen, and Lower Darwen, and Nova Scotia.

Over Darwen.—Population, 29,747; constant supply from reservoir; rateable value, 73,156*l.* 11*s.*; Darwen Waterworks Acts, 1847 and 1869. Rainfall observed at St. James's Vicarage, 564 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
50·33	68·41	47·15	45·93	46·65

The average fall of the last 8 years is 51·17 inches.

Witton or Blackburn Brook.

The *Darwen* receives a tributary on its right bank, which flows in the direction of the strike of the Fenniscowles synclinal, afterwards traversed by the *Darwen*. The town of Blackburn extends on its left bank for a distance of nearly 2 miles. A tributary stream comes into *Witton* Brook at Little Harwood from the south, draining the Lower Coal

Measures at Belthorn, and another from the north draining the Millstone Grits.

Blackburn.—*Acres*, 4071; population, 104,012, with Borough Extension about 93,371; rateable value, 259,805*l.* 10*s.*, borough only, exclusive of outer district of supply; supply under Blackburn Waterworks Acts, 1845, 1849, 1861, and 1875; Blackburn Borough Gas, Water, and Extension Act, 1875; constant supply of about 2,000,000 gallons from streams and surface drainage.

Rainfall taken by Mr. Bryan, C.E., in Blackburn Waterworks District.

	Waterworks Office, above sea-level, 400 feet.	Preston New Road, 515 feet.	Witton, 315 feet.	Guide, 650 feet.	Pickup Bank, 720 feet.
1875	..	..	..	39·70	39·30
1876	45·47	..	..	42·50	47·60
1877	58·22	..	59·23	59·80	70·50
1878	36·31	45.88	41·05	42·40	44·50
1879	32·66	39·80	35·26	35·62	..
1880	38·73	45·34	41·57	40·29	44·97

Rainfall in 1880, at Dunsop Houses, 450 feet above the sea, 58·18; at Whitendale, 830 feet, 65·30 inches; at Cabin Hill, 1559 feet, 63·50 inches; at Middleknoll, 1298 feet, 49·70 inches; at Baxton Fell, 1540 feet, 49·60 inches.

The last Act obtained gives power to abstract water from the upper feeders of the *Hodder*, east of those taken by Preston, viz. *Brennand* and *Whitendale* Brooks.

The watershed between the *Darwen* and the *RIBBLE* runs along the strike of the Kinderscout Grit at Mellor, and crosses the fault bringing in the Pebble Beds at Rowley Fold, ranges along the high-road to Walton-le-Dale, where the Glacial Drift area, intervening between the two rivers, narrows to a sharp ridge resting on rock, at the top of which is Walton Church.

Walton-le-Dale.—*Acres*, 1683; population, 9286; rateable value, 37,682*l.*; artesian well in Millstone Grit, now

sinking at the Walton summit-level, to supply 150,000 gallons of water. The site was chosen by myself as likely to afford water free from organic impurity, and to give sufficient pressure in case of fires, at the mill property.

The left bank of the *RIBBLE* flows over a surface of Pebble Beds to a north-west fault bringing the Millstone Grits to the surface, which continue for a short distance, and the underlying Yoredale Beds rise to the surface, consisting of Upper Grit, black fossiliferous "Bolland Shales"; Lower Grit, which in Pendle overlie Yoredale Limestone; Shales, with Limestone, and the Carboniferous Limestone. Various feeders drain the Drift-covered country to the south, but the principal stream has a U-shaped course, rising at well-springs or the Kinderscout Grit at Bellington Moor End, then it trends south-west over the overlying Shales, which it recrosses near Ribchester Station, flowing west-north-west, at *Showley* Brook, over the Yoredale anticlinal, to Haywood Fold, where it turns to the north-east, and flows to the *RIBBLE*, as *Park* Brook, falling in west of the infall of the River *Calder*. The valley here is above half a mile across.

River Calder.

Length, 18 miles; area, 130¾ square miles; population of the basin in 1801, 36,826, in 1861 it had reached 118,725.

The course of the stream from its infall is at right angles to the strike of the various Yoredale and Millstone Grits through which the river has cut a gorge, at the bottom of which are glacial striæ, in the direction of the present stream.

A stream, the *Hyndburn*, comes in on the left bank, one of whose feeders rises at Warcock Green and flows past Oswaldtwistle, uniting with another feeder rising at Haslingden Moor, above sources of tributaries of the *Irwell*, at Church, and falls into the stream that has drained the Accrington district. Between Church and Clayton-le-Moors the Accrington stream is formed by a western feeder rising at Baxenden and an eastern flowing through Warmden Clough, and

then through the town of Accrington; all these streams drain a Lower Coal Measure area, but little obscured with Drift.

The watershed separating the *Calder* Basin from the *RIBBLE* runs along the escarpment of Rough Rock and Third Grit to Windy Bank, where it forms the watershed separating the waters of the *Darwen* from those of the *Calder* which terminates against it. The latter watershed trends south to Shin Bone Hill, Haslingden Moor, passing west of the Rishton reservoir impounding a stream flowing into the *Calder* below Clayton-le-Moors. The Leeds and Liverpool Canal passes into the *RIBBLE* Basin between Hoghton and Withnell at 360 feet above the mean sea-level, thence it crosses the *Roddlesworth*, the *Darwen*, and the *Calder* watershed, near Rishton reservoir; at Rishton it is 420 feet above the sea, and contours the Church Valley, and then passes into the Burnley Coalfield basin.

Oswaldtwistle.—*Acres*, 4883; population, 12,206; rateable value, 35,268*l.*; constant supply from drainage area of 288 acres of 380,000 to 442,000 gallons, stored in two reservoirs of 12 acres; Local Government Act, 1858; Provisional Order, 2nd April, 1864.

Accrington.—*Acres*, 3425; population, 31,435; rateable value, 93,672*l.* 10*s.*; constant supply from catchwater reservoir at *Dean* Brook, above the town; filtered; Accrington Gas and Waterworks Company's Acts, 1854, 1863 and 1869.

Accrington Waterworks Company supplies the following Local Authorities:—Clayton-le-Moors, *acres*, 937; population, 6694; rateable value, 16,155*l.* 5*s.* Great Harwood, *acres*, 2616; population, 6281; rateable value, 15,473*l.*

Following the River *Calder* up stream, east of the infall of the *Hyndburn*, it enters the Middle Coal Measures, and trends east-north-east to the infall of the River *Lamshaw*, where it returns to the north-west and south-east trend, which continues past Burnley and Holme to its source in the col at Thieveley, west of Todmorden. The source at Calder Head is 1¼ mile

to the north-east of Ere Well, the source of the *Irwell*, and close to the source of the Yorkshire *Calder*.

Following the right bank of the *Calder* from its source, it flows past Cliviger to Burnley, where it receives the River *Brun*, rising on the Pennine watershed between Hazel and Sheddon Edges to the west, and Black Hambledon to the east, the latter overlooking the watershed of the *Halifax Waterworks*. The Pennine or anticlinal fault in the upper part of the Saddleworth Valley becomes split up into several branches, ranging north-north-west through Denshaw; crossing the area drained by the head waters of the *Tame* into the basin of the *Roach*, the faults die out, except one ranging on the west side of Blackstone Edge. It is here a downthrow west, as it is further south, but is rather a synclinal than an anticlinal fault. At Todmorden the fault throws Yoredale Grit against Third Grit Shales. Still further north, the fault passes into the *Calder* Basin, and throws Kinderscout Grit against the shales of the Third Grit, the beds on both sides dipping west. The underground drainage of the Yorkshire side of the watershed is, however, not carried into the *RIBBLE* Basin, for the Black Hambledon watershed traverses an anticlinal parallel to the fault, and the beds then dip east, down the stream of the Yorkshire rivers. East of Rams Clough and Hazel Edge, the fault changes the direction maintained from Central Cheshire, and trends eastward of north, and dies out in the Millstone Grits of the Forest of Trawden; the east-north-east strike of the Yoredale Beds being unbroken, where the line of dislocation would have occurred, between the basins of the *RIBBLE* and the *AIRE*.

On the right bank of the River *Brun*, it receives a stream draining Worsthorne, and the Millstone country of Hazel Edge. North of Rowley Bridge, it receives the River *Don*, rising at Robin Hood Well, on Boulsworth Hill, on Yoredale Shale, near the *Halifax Waterworks'* watershed. Thence it flows down the dip of the strata, crossing the Millstone Grit and Lower Coal Measures, and entering the Middle Coal

Measures south of Haygate, receiving on the left bank *Swinden* water draining Entwistle Moor and Ham.

Rainfall observed by Mr. Bryan, C.E., in Burnley District.

	Burnley, 450 feet.	Rose Grove, 493 feet.	Brierfield, 402 feet.
1875	..	39·55	38·72
1876	38·86	42·00	38·95
1877	49·32	57·48	55·78
1878	36·86	40·41	40·10
1879	33·41	38·29	37·37
1880	38·21	42·41	52·26

Burnley.—*Acres*, 1018; population, 58,882; rateable value, 115,540*l.*; supply from gathering and surface springs in Entwistle and Worsthorne townships, stored in three reservoirs, yielding 1,229,349 gallons of unfiltered water; under 9 & 10 Vict. c. 119; 17 & 18 Vict. c. 67 (both repealed); and "The Burnley Borough Improvement Act, 1871."

Burnley Waterworks District, Rainfall observed by Mr. J. Emmett.

	Waterworks, 420 feet above the Sea.	Swinden Reservoir, 750 feet above O.D.
1878	34·58	43·00
1879	..	31·11
1880	..	36·37

A large area is drained by the River *Henburn* and its tributaries, falling into the *Calder* at Royle. Its left bank drains the district of Marsden, Hebson, Catlow, Southfield, and under the name of the River *Lamshaw*, its feeders traverse the Millstone Grit of the Forest of Trawden, including Trawden, Winewall, and Wycoller.

Colne and Marsden.—*Acres*, 5331; population, 11,970; rateable value, 30,527*l.*; intermittent and insufficient supply

from reservoirs of *Colne Water Company;* Colne Water Act.

NELSON.—*Acres,* 822; population, 10,381; rateable value, 18,300*l.*; constant supply of 160,000 gallons from three brooks flowing into *Walverden* water, which stream is impounded by the Local Authority, under their Acts of 1866 and 1878, in a service reservoir holding 2,000,000 gallons, and a storage compensation reservoir for millowners on the stream, holding 25,000,000 gallons.

A tributary stream falls in on the right bank between Colne and Lawerford, draining the col valley connecting the basin of the Lancashire *Calder* with the Yorkshire *AIRE,* at the head of which are the reservoirs of the Leeds and Liverpool Canal, situated on the shales separating the Kinderscout and Upper Yoredale Grit, and on the Sabden Shales overlying the Kinderscout Grit.

Another feeder rising on the Upper Yoredale Grit, on Burn Moor, at the eastern end of the Pendle Hill, flows over the Millstone Grit of the Forest of Pendle, and falls into the right bank of the *Lawerford.* Following the latter stream on its right bank, it enters the Middle Coal Measures of the Burnley Coalfield, at Old Laund Hall, near Whateley Lane, and flows over them to the infall of the stream into the *Calder,* north-west of Burnley; they continue on the right bank of the *Calder,* by Padiham, the river following their strike, until a fault, ranging through Simonstone Hall, cuts off their western extension. A little further west the *Calder* changes its direction, and cuts a gorge, first through a ridge of Millstone Grit, ranging east-north-east, and then through the higher and parallel ridge of older Yoredale rocks; between the two ridges is the valley drained by *Sabden* Brook, running over the shales, named after the village. The Sabden Shales occupy a horizontal space on the dip, of nearly three-quarters of a mile, resting on the Kinderscout Grit, which is only separated from the Upper Yoredale Grit by a thin band of shale. The Lower Yoredale Grit and underlying Pendleside Limestone are absent here,

and the Lower Yoredale Shale occupies a large tract, extending to and beyond the *RIBBLE*, which the *Calder* joins at 102 feet above the mean sea-level near Mitton Wood.

Padiham and Hapton.—*Acres*, 937; population in 1881, 8983; rateable value, 18,151*l.* 10*s.*; constant supply from reservoir storing surface water; Padiham Water Act, 1874.

Following the left bank of the *RIBBLE* towards its source, a tract of Permian Sandstone and Marl, about 1½ square mile in extent, rests on the Lower Yoredale Shales, at Low Moor, near Clitheroe, where an anticlinal throws up the Carboniferous Limestone ranging north-east by Chatburn and Downham.

Clitheroe.—*Acres*, 2017; population, 10,177; rateable value, 30,263*l.*; constant supply of 256,700 to 266,000 gallons from service reservoir, holding 500,000 gallons, impounding streams flowing off Fells in the townships of Grindleton and West Bradford, five miles west of Clitheroe.

At the close of the Carboniferous period the British Isles, in common with the neighbouring parts of Europe, were subjected to great lateral pressure, acting in a general north and south direction, which produced considerable terrestrial movements in the earth's crust, causing the strata to be thrown into a series of flexures, ranging in a direction at right angles to that of the pressure exerted. In France, Belgium, the South of England, and in Yorkshire, the direction of the axes of these flexures is nearly east and west; in Lancashire, in the hills of the Pendle range, east-north-east (E. 35 N.). The most important of these rolls or anticlinal axes now traverses the Yoredale Rocks and Millstone Grit separating the Lancashire and Yorkshire Coalfields from that of Durham. These anticlinal arches, more or less traversed by fissures, were readily attacked by denudation, and it is due to this cause that anticlinals are found along the lines of the valleys, while synclinals occur in hills forming lines of strength. It was by this denudation, at the

close of the Carboniferous Epoch, that so large an area of Coal Measures were swept away.

The sections that have been drawn by the Geological Survey across the South Lancashire and Burnley Coalfields, and the surrounding tracts of older carboniferous rocks, well exhibit the series of flexures or foldings that the rocks of the Pendle range have thrown by lateral pressure. These flexures traverse the country in a series of wave-like curves, the axes of which travel in an east-north-east and west-south-west direction, and form the Sykes, Slaidburn, Clitheroe, and Rossendale Anticlinals of Messrs. Hull and Tiddeman.

The lines of the geographical valleys range through the anticlinals, as the valley of Sykes, Slaidburn, and Clitheroe, while the synclinals traverse the fells and hills intervening. The curve of the Rossendale Anticlinal, ranging through the ancient forest of that name and through Anglezark Moor, is low and gentle, and north and south of it lie respectively the Wigan and Burnley portions of the Lancashire Coalfield, which lie in basins, true synclinals of deposition in the past, and forming geographical valleys at the present time. An examination of the thicknesses of the strata lying between the well-marked and well-known coal-seams of the Middle Coal Measures enables the relative rate of movement, as well as its position and duration, to be ascertained, which was the first expression of the continued subsidence that brought about those flexures which separated the Lancashire Coalfield into distinct tracts.

The Carboniferous rocks of this area consist of the following sequence, in ascending order:—

Mountain Limestone.—The base is seen resting on Silurian rocks in the valley of the *RIBBLE*, north of Settle, near Malham Tarn. At Clitheroe the bottom beds are not brought to the surface by the anticlinal, and the thickness without these is no less than 3250 feet. The limestones of the Forest of Pendle are of great value for their lime-producing

qualities, both the lower black bituminous varieties and the upper grey beds, the former being the most desired when whiteness is an object, the whole of the colour being expelled by burning.*

Shales with Limestone.—These series consist of an alternation of shales, thin limestone, cement stone, and thin ironstones, giving rise to springs containing sulphuretted hydrogen gas; one of these occurs at Clitheroe, and has a bath-house attached. The thickness of this series is not less than 3225 feet.

Lower Yoredale Grit.—This bed resembles the Gannister beds of the Coal Measures in appearance and hardness; it is often absent; but, when present, it invariably forms the base of the Bowland shales, so named by Professor Phillips, and plays an important part in the scenery of the Forest of Pendle, the steep slopes of which are all composed of the disintegrating shales of this age, reaching a maximum thickness of 700 feet. The most common fossil is *Posidomya Gibsoni;* Goniatites and fish remains occur, as well as seams of ironstone, which give the shales an appearance of Coal Measures, which has led to many fruitless borings.

Upper Yoredale Grit is well seen in the quarries at Longridge Fell, near Preston, which are very extensive, the grit reaching a thickness of not less than 1000 to 1200 feet. Overlying the Upper Yoredale Grit, which contains impressions of plants, occurs a bed of shale 200 feet in thickness, on which rests the Kinderscout Grit, forming the base of the Millstone Grit Series, which is divided into four great divisions by three thick beds of shale, and these beds are often again subdivided by intercalated shales, often of considerable thickness. These sub-divisions, though useful for purposes of identification in Derbyshire, Lancashire, and South-Western Yorkshire, are local, and mere divisions of

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* 'Memoirs of the Geological Survey.' Mr. R. H. Tiddeman, in the 'Geology of the Burnley District.'

convenience, the whole of the Millstone Grit, physically and biologically, forming one formation.

Various small streams drain the back of Pendle Hill, which rises to 1831 feet, and fall into the left bank of the *RIBBLE*, chiefly rising on the Bowland Shales, intervening between the Yoredale Grits. The most important is *Ings Beck*, which constitutes the county boundary, both banks of the *RIBBLE* being in Yorkshire above the infall of this stream near Sawley. The north-east trend of the *RIBBLE* valley, commencing at Preston, is continued to Gisburn, when it turns first northward, and then north-north-west, running close to the Pennine watershed by Long Preston, Settle, and Horton-in-Ribblesdale, to its source east of Wharnside.

Following the *right* bank of the *RIBBLE* from its source through Ribblesdale, no place of importance is passed until Giggleswick is reached, at the entrance of the valley. At Bolton-by-Bowland a feeder comes in from the north, draining Yoredale rocks, and several smaller streams between its infall and that of the important tributary the *Hodder*. These streams drain the high moors above Grindleton, Waddington, and Great Milton, where the infall of the *Hodder* occurs at 120 feet above the sea. The Yorkshire county boundary follows the *RIBBLE* from the infall of *Ings Beck* to that of the *Hodder*.

River Hodder.

The *Hodder* is 18 miles in length, its valley being coincident in direction with that of the *Calder*. It drains 103½ square miles of Yoredale rocks, which were inhabited in 1861 by 3388 persons. The left bank of the *Hodder* is situated wholly in Yorkshire, the county boundary following the river to a point a little above Whitewell, where it crosses the stream, and, passing over the right bank of the basin, ascends the Bleasdale Fells, and follows the watershed. No streams of importance drain the left bank.

Feeders on the right bank of the *Hodder*, below Newton, in Whitendale and Brennand valleys, are to be impounded for the additional supply of Blackburn, by powers granted by an Act passed in 1880. The *River Langden* and its tributary, *Hareden Brook*, draining the wild valleys on the west side of the Sykes col valley, are impounded by the *Preston Corporation Waterworks*, the conduit being laid on the west side of the *Hodder*, through Chipping and Longridge.

River Loud (tributary of the *Hodder*).

The watershed separating the basins of the *WYRE* and *RIBBLE* ranges south from Fair Snape, 1701 feet above the sea, through Parlick Pike, 1476 feet, then south-west to Beaton Fell, 674, whence it trends south-south-east to Longridge Fell, descending to less than 400 feet in the very fine col valley separating the Bleasdale and Longridge Fells. Looking down the valley of the *Loud*, from its source between Beaton and Parlick Fells, the watershed is hardly noticed, and the natural course of the stream appears to be to the south into the basin of the *WYRE*, but at Loudscales the stream turns and, describing a U-shaped course, flows to the north-east, following the strike of the Yoredale Rocks, and falls into the *Hodder* near Chipping.

The right bank of the *RIBBLE*, from the infall of the *Hodder*, flows at the foot of Longridge Fell, which is composed of the Upper and Lower Yoredale Grits, separated by Shale, and dipping under the Millstone Grit, traversed by the river. At the north end of the Fell is Stoneyhurst College and the ancient village of Ribchester, at the south end is the village of Longridge, near which are the quarries above referred to, in the Upper Yoredale Grit, largely used at Preston as a building stone. Westward, the Glacial Drift gradually increases in thickness, and extends to the sea, and southwards over the whole of the district called the "Fylde," in the basin of the *WYRE*. Rainfall observed

at Stoneyhurst College by the Rev. S. J. Perry, at 376 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
47·51	60·30	45·36	42·39	50·27

At Red Scars, near Grimsargh, the triplex arrangement of the Glacial Drift is well seen, true Boulder Clays being separated by a Middle Sand. Westward, they are more or less obscured by landslips, terraces of old alluvium, and grass. Good sections of laminated Clays and Middle Sands have recently been exposed in the construction of the new railway station at Preston. The Upper Boulder Clay forms the surface of the country westward by Lee, Ashton, Lund, and Freckleton, where there is a good cliff section at the Point. Here and there the Middle Sands come to the surface through the Upper Boulder Clay, as at Kirkham. In the district west of this place, at Moss Side, the surface of the Glacial Drift sinks beneath high-water mark, and the country is covered with peat moss, extending up to Southshore, near Blackpool, bounded to the north by a bluff of Boulder Clay, and southward by the sea, fringed with a range of Sand Dunes, commencing at Lytham, and extending through St. Anne's to Southshore. The district lying between Preston, Lytham, and Southshore is about 40 square miles in extent; it drains entirely into the tidal estuary of the *RIBBLE*, and can hardly be considered within the basin of that river.

Preston.—*Acres*, 2820; population, 96,532; rateable value, 265,000*l.*; constant supply of 2,700,000 to 5,000,000 gallons from gravitation waterworks; springs and gathering-ground near Longridge, 6 miles from Preston, stored in Alston reservoir, holding 73,000,000 gallons; Spade Mill, 110,000,000 gallons; Grimsargh, 59,000,000 gallons; Dilworth, 24,000,000 gallons; supplemented by water occasionally pumped from the River *Loud* and *Cowley* Brook; impounding works in *Langden* and *Hareden* Brooks, at Sykes, tributaries of the *Hodder*, 14 miles from Longridge; the

water is passed through wire sieves; works under Preston Waterworks Act, 1863; and Preston Improvement Act, 1869.

Rainfall at the *Preston Waterworks* Office, 100 feet above the sea, for the past thirty-two years:—

Year.	Inches.	Year.	Inches.
1849	34·03	1865	30·84
1850	35·07	1866	50·05
1851	32·92	1867	34·83
1852	43·94	1868	37·78
1853	30·98	1869	44·61
1854	34·86	1870	39·51
1855	27·70	1871	34·11
1856	33·09	1872	53·10
1857	32·89	1873	38·18
1858	30·51	1874	43·23
1859	36·05	1875	34·11
1860	37·86	1876	37·15
1861	35·90	1877	52·40
1862	41·76	1878	35·71
1863	42·10	1879	32·71
1864	32·30	1880	36·36

The average rainfall at Preston, from 1851 to 1865, was 34·84 inches, and from 1866–80 was 37·84, showing an increase of average annual rainfall of 3 inches.

In 1880, Mr. Hudson Reah, C.E., states, the rainfall at Jeffrey Hill was 47·52 inches; at Knowl Green, 42·14; at Spade Mill, 40·03; at the River *Loud*, 42·97; at Alston, 41·14; at Langden, 66·52; at Hareden, 67·34.

Fulwood.—Population, 3725; rateable value, 15,104*l.*; constant supply at present from Grimsargh reservoir of the Preston Corporation, who have no Parliamentary powers to supply. A boring in the New Red Sandstone is now being carried out, and has reached a depth of 250 feet, for an independent supply at a site chosen by me. The water obtained is free from all organic impurity.

Kirkham.—*Acres*, 857; population, 3840; rateable value, 9069*l.*; constant supply from *Fylde Waterworks Company's*

reservoir at Scorton, in the Grizedale Fells, in the basin of the *WYRE*, south-east of Lancaster; under 24 & 25 Vict. and 33 & 34 Vict. The Company also supply Garstang, Lytham, Blackpool, and Fleetwood, and are now seeking further powers.

LYTHAM.—*Acres*, 659; population, 4122; constant supply from *Fylde Waterworks Company;* rateable value, 16,690*l.* 14*s.* Rainfall:—

1878.	1879.	1880.
33·36	34·32	32·19

ST. ANNE'S-ON-SEA.—*Acres*, 220; population, 1179; rateable value, uncertain; district only just formed; supply constant, from *Fylde Waterworks Company.*

RIVER WYRE (XLI.).

Length 24 miles; area, 208 square miles, of which Yoredale Grits and Shales occupy 80 square miles, Permian Sandstones, 18; and Keuper Marls, 110. The sea frontage of this basin is considerable, extending from Southshore to Rossall Landmark, and from there to Pilling, a distance of 15 miles.

The coast drainage between Blackpool and Rossall Point passes directly to the sea, and constitutes a small separate drainage area of about 8 square miles, which tract consists of Upper Boulder Clay resting on the Middle Sands, which appear in the cliffs, and occasionally comes to the surface. The rainfall received in this area is quickly conveyed to the sea over the sloping surface of the clay, or pours down vertical joints in it to the sands beneath, which discharge a portion of it in a line of springs at the base of the cliffs, flowing through the shingle between tide-marks.

BLACKPOOL.—*Acres*, 2358; population, 14,448; rateable value, 85,000*l.*; constant supply from the *Fylde Waterworks Company.* The Corporation would prefer sale by meter to them, so that they should undertake the distribution.

Rainfall observed by Mr. Geo. Sharples, 29 feet above the Sea.

	First Half-year.	Second Half-year.
1870	11·12	20·29
1871	10·93	19·01
1872	19·35	28·00
1873	12·00	14·27
1874	8·76	20·97
1875	11·03	22·90
1876	10·72	22·05
1877	19·25	30·12
1878	13·50	18·42
1879	13·80	17·80
1880	11·50	23·22

The average rainfall for the last twenty-five years is 32·88 inches. Of the 34·72 inches of rainfall in 1880, 25·22 inches were evaporated.

Fleetwood.—*Acres*, 2900; population, with Thornton, 6513; supply from *Fylde Waterworks Company*.

Following the left bank of the *WYRE*, up stream, from Fleetwood, a tract of tidal alluvium forms the narrow strip of land between the sea and the estuary of the river; much of it is somewhat below spring-tide high-water mark, and both sea and river are artificially kept out; but the sea-walls are considerably destroyed, and in very bad condition. Wells at Cleveleys produce brackish water. The river widens out southwards, and presents a wide expanse of tidal waters, contracting at the point where they are crossed by Shard Bridge, above which the tide flows for a considerable distance. *Thistleton Brook* and other feeders falling into the left bank drain the flat country around Poulton-le-Fylde, Thistleton, Eccleston, Wharles, and Inskip, consisting of Upper Boulder Clay resting on sands. Nowhere is the rock seen; but Keuper Marls have been proved under the Glacial Drift in a boring at Poulton to a depth of 179 yards. Rainfall at Elswick Lodge, 50 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
35·85	51·17	35 59	32·21	33·08

Stalmine registration sub-district contains 13,589 *acres*, with a population of 3281. Poulton-le-Fylde registration sub-district contains 20,863 *acres*, and a population of 25,346.

River Brock.

At St. Michael's-on-Wyre, the river receives the River *Brock*, 10 miles long, which a little east of the vicarage is joined by, on its left bank, *Woodplumpton* or *Blundel* Brook, rising near Longridge, at an elevation of 350 feet, and flows between Grimsargh and Goosnargh, through a Drift valley, resting on Yoredale rocks, past Broughton, Woodplumpton, and Woodsfold. At Carver's Bridge this brook is joined by *Barton* Brook, draining east of Barton Lodge, Yoredale rocks first appearing at 150 feet above Ordnance Datum on this stream near Mackareld House, and 175 feet on its tributary *Westfield* Brook. The watershed between these streams and the *Loud* rises to 425 feet.

Following the left bank of the *Brock*, up stream, from the infall of this brook, it passes under the Lancaster Canal at 70 feet, under the London and North-Western Railway at Brock Station, east of which it crosses the fault throwing up the Mudstones of the Yoredale series, appearing beneath the Drift at 100 feet above the mean sea-level.

The direction of the River *Brock* valley is continued by the *WYRE* from St. Michael's to Poulton-le-Fylde, through a valley cut in the Glacial Drift, forming steep cliffs of no great height at Shard Bridge. Before the deposition of the Cleveleys Estuarine deposits and the underlying peat, the river probably continued flowing in this direction, and reached the sea at Cleveleys, or at a point further seawards, as the coast has been and is rapidly wearing back by tidal erosion. East of St. Michael's the *WYRE* valley turns north-eastward, passing Churchtown, which is built on Boulder Clay resting on Permian Red Sandstone.

St. Michael's registration sub-district includes 16,439 *acres*, with a population in 1881 of 3184.

River Calder.

This river is 8 miles long; rising in the Yoredale rocks of Luddock's Fell, on the watershed of the *Hodder*, overlooking Fiendsdale, 1500 feet above the sea, it flows south and south-west through a deep gorge, emerging on to the plain near Garstang Railway Station, and falls into the *WYRE*, opposite Garstang Church, at about 30 feet above Ordnance Datum.

The tops of the Bleasdale and Grizedale Fells consist of sweeping undulations, in the bottoms of the hollows of which occur trough-shaped brook and river valleys, with steep sides; the *Calder* receives its first waters from brooks running over the surface of the upland, undulating, peat-covered plain to the north-east of Winny Hill. The levels of the sources of these streams are from 1485 to 1350 feet above the mean sea-level. These brooks, and the small tributary rills running into them, flow at the bottom of small trenches or slots of various depths, from 3 inches to 15 feet, excavated in the peat down to the underlying deposits of rain-wash, which they have seldom fall enough to denude. On the lower slopes of the Fells, however, and here and there on the summit-levels, where the slope is considerable, the rush of the rain under the peat has fairly lifted it up, carried it away, and left a vacant space of bare rain-wash, scattered here and there with loose stones, often many pounds in weight, borne from above. These bursts, or "brasts," as they are called in the Lancashire dialect, generally appear to have exerted that force with greatest intensity at one point, below which it radiated out in a fan- or cone-shaped area, the apex pointing upwards. The peat-cleared tracts have generally become the storm-channels of the water falling on the upper slopes, or rather that portion which is in excess of the soakage powers of the peat to hold back. These storm-waters, exuding between the peat and the rain-wash, rush with great violence over the Fell-sides, carrying stone and earth derived from the latter. Most of this is carried into the brooks below, but some is spread over the peat-cleared

areas, which thus become stony deltas of apparently invisible streams, draining a tract of country in which a loose stone is never seen.

It is clear that if one of these brooks running under the peat, over a flattish country, should flow over an undulation, the slope of which is less steep than that from the point where the stream enters the slope to the level of the base, it will form itself a trench or valley of a depth equal to the number of feet between the two points.

The *Calder* crosses the fault, throwing in the Permian Sandstone at Sandholme Mill, and falls into the *WYRE* above Garstang Church; its south-west trend is continued by the *WYRE*, as far as the infall of the *Brock*.

The valley of the *WYRE*, from the infall of the *Calder*, trends northward through a broad valley excavated in the Glacial Drift at Garstang, and then through a deep valley in the Yoredale rocks at Scorton.

Grizedale Brook.

This tributary falls into the *WYRE* between Garstang and Scorton: it rises at Grizedale Head, 1200 feet above the sea, north of the source of the *Calder*, and flows entirely over Yoredale rocks. It is impounded in the picturesque valley, called Nickey Nook, by the *Fylde Waterworks Company*. The Yoredale Grits are shattered and faulted, and it is found difficult to render the reservoir watertight. Another reservoir has been constructed on the hill to the south. The rainfall, at 519 feet above the sea, was:—

1876.	1877.	1878.	1879.	1880.
44·67	59·40	37·76	39·32	44·56

On the right bank of the *WYRE* a large area drains directly into Morecambe Bay, a low watershed traversing Cockerham Mosses, drained by the River *Cocker* and River *Pilling*. Under the peat moss is a raised beach, which is well seen at Preesall. The Preesall shingle thins out eastward, against a slope of Glacial Drift, west of Garstang.

The town is built on Glacial Drift resting on Permian Red Sandstone, in which is a well at Higher Crookey.

Rainfall at Vale House, Garstang, 455 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
44·71	61·50	41·50	38·46	43·38

Average of the past 18 years, 44·83 inches; average rainy days, 199.

Garstang registration sub-district contains 31,087 acres, with a population of 5833.

The *Lancaster Corporation Waterworks* take the upper portions of the feeders of the *WYRE* for their town supply, and the remainder, including *Tarnbrook Wyre* and *Marshaw Wyre*, forms their compensation water area for millowners who have a private reservoir lower down the *WYRE*.

Mr. Jackson, C.E., proposed the upper *Brock* as a source of water-supply for Liverpool; he proposed to make a reservoir at Admarsh, with an embankment 110 feet in height, which he calculated to yield a daily supply of 30,000,000 gallons, derived from 4250 acres drained by the *Brock*, and 6000 in Wyredale, and some feeders of the *Loud*, not appropriated by the *Preston Corporation Waterworks*.

CHAPTER XXXIII.

THE NORTH LANCASHIRE BASINS.

RIVER LUNE (*XXXIV.*).

Length, 42 miles; area, with tributaries, 418 square miles, of which about 104 square miles consist of Silurians, 144 of Carboniferous Limestone, 168 of later Carboniferous rocks, chiefly Yoredales, and 2 of Permian Sandstone.

The watershed trends east from the mouth of the river, over the crest of the Grizedale Fells, forming the northern margin of the *WYRE* and part of the *RIBBLE* Basin. West of Settle the watershed turns abruptly north, running parallel to the *RIBBLE*, over the ridge of Whernside, 2414 feet high, to a point west of Hawes, where it falls into the central Pennine watershed, separating the eastern from the western rivers. This it follows for a distance of only 2 miles, overhanging the head waters of the *URE*, after which it trends a little north of west, and separates the upper basin of the *LUNE* from the head waters of the *EDEN*, that river, the *LUNE*, and the *RIBBLE* rising within a few miles of each other. The northern boundary of the *LUNE* Basin is formed by the great east and west watershed traversing the north of England in nearly a straight line, with the exception of the southern deflection produced by the occurrence of the remarkable valley of Mallerstang, in which rise the *EDEN* and the *URE* within a quarter of a mile of each other. The watershed from Mallerstang, skirting the *EDEN* valley, crosses Ravenstonedale Common to Ashby Winderworth Common, and trends west over Shap Fells; the watershed generally coinciding with the division between townships, it is crossed by the London and North-Western Railway at Hardendale Fell, south of Shap Station,

which district is drained by the head waters of the *Lowther* draining into the *EAMONT.*

On Shap Fells, the margin of the *LUNE* Basin leaves the east and west watershed and trends south-east, separating the waters of the *KENT,* running by Grayrigg Forest, after which it runs south, parallel and close to the *LUNE* by Kirkby Lonsdale.

South of Kirkby Lonsdale it trends to the west of south, the watershed continuing parallel to it, by Hutton Roof and Arkholme Moor, 466 feet above Ordnance Datum, where it separates this Basin from the waters of the River *Keer* flowing into Morecambe Bay, and then crosses the peninsula intervening between the sea at Morecambe and the estuary of the *LUNE.*

The outlet of the *LUNE* between Sunderland Point and Chapel Hill is less than half a mile across. Between Trailholme and Old Glasson it widens to a mile and a quarter, again contracting to two-fifths of a mile between Bazil Point and Glasson, east of which it trends north to Lancaster with an average width of three-quarters of a mile. At Glasson there is a small dock at which terminates a branch of the Preston and Lancaster Canal. East of it, is the infall of the River *Gonder,* rising east of Lancaster, at 450 feet, and flowing south-west by Galgate, Sellerley, and Gonder Green. Following the left bank of the estuary by Ashton Hall Park, a small tributary comes down from the Racecourse, and passes on the east side of Scotforth, Glacial Drift here overlying Lower Carboniferous Sandstones.

Following the left bank of the *LUNE,* the town of Lancaster with its Castle is built on a terrace of Glacial Drift lying at the foot of the Fells of Carboniferous Sandstones and Shales, occupying the whole of the country up to Settle, south of the River *Greet,* and between that stream and the *LUNE* at Kirkby Lonsdale.

LANCASTER.—*Acres,* 1240; population, 20,724; supply from gravitation works collecting moorland springs on Grizedale Fells, about 8 miles distant; rateable value,

63,012*l.* Analysis made by the Rivers Pollution Commission gives 4·18 of total solid impurity; organic carbon, 0·235; nitrogen, 0·050; ammonia, 0·001; chlorine, 0·79; hardness, 2·7, all of which is permanent. Works under Lancaster Water and Gas Act, 1852; Amendment Act, 1855; Lancaster Local Board of Health Act, 1864, and Water and Improvement Act, 1876. Rainfall in 1880, 38·87 inches; average of 20 years, 40·87 inches; the average maximum monthly rainfall was in August and September, being over 4 inches; the minimum average was in April 1·92 inch. The annual average number of wet days in 14 years was 182.

The Lancaster Canal crosses the river at Dolphinlee, about a mile above the town, in the Bulk Road Aqueduct. Higher up the stream, east of Three Mile House, the river has a very sharp bend, and receives *Arth Beck* at Caton. This stream has two strong feeders, *Udale Beck* and *Foxdale Beck*, rising on the Littledale Fells, which form the *WYRE* watershed, rising to 1656 feet at Wards Stone.

The *LUNE*, at the infall of this Beck, trends south-west and north-east, winding through an alluvial plain 50 feet above the sea, rising to 75 feet at Hornby, west of which is the infall of the River *Wenning*, 15 miles in length. At the edge of the plain are the villages of Caton Green and Claughton, and the Midland Railway line. A mile and a half from the outfall of the *Wenning*, it receives the River *Hindburn*, which, with the River *Roe*, flowing in on the left bank at Wray, drains the wild moorland grit-country forming the *RIBBLE* Basin watershed in the Forest of Bolland, rising to 1731 feet at Woolfhole Crag.

River Wenning.

This river, 15 miles in length, rises west of Settle, near the *RIBBLE* watershed, and drains entirely Lower Carboniferous Sandstones and Shales. Following the *Wenning* from its source, it drains the southern slopes of the Carboniferous Limestone hills, forming part of Ingleborough, 2378 feet, the picturesque country above Clapham, with its

caves and subterranean streams, and passes by Low Bentham, Wennington, and Hornby, to the *LUNE*.

Further north, near Wrayton, a little below the 100-feet contour, is the infall of the River *Greet*, about 11 miles in length, rising in the deep valley between Whernside, 2414 feet, and Ingleborough, a feeder draining the north-west side of the mountain falling in at Ingleton.

At Burton-in-Lonsdale, or Black Burton, about 4 miles from the *LUNE*, the stream crosses a small coalfield, cut off to the north-east by the Great Craven fault, bringing up the Lower Carboniferous rocks. It is described by Mr. Tiddeman as partially overlaid by Permian Red Sandstones and breccias, and as resting on Yoredale and Millstone Grits, the whole being somewhat obscured by Glacial Drift, Clay, and Sand.

From the infall of the River *Greet* at Teinstall, numerous small streams drain the steep sides of the Barbon and Casterton Fells, rising to 2000 feet, at the foot of which are the villages of Ireby, Overtown, Casterton, Whelprigg, and Barbon. Where *Barbon* Brook has cut a deep gorge between the Barbon and Middleton Fells to the north, the stream falls into the *LUNE* at about 175 feet, it rises at 975 feet, falling 800 in 6 miles, or 133 feet per mile. It has cut back its gorge to within a mile of the River *Dee*, a tributary falling into the *LUNE* higher up the stream. The gorge is continued to the *Dee* valley, down to the 1000-feet contour. Below this, feeders of the *Dee* flow north, down the side of the *Dee* valley falling in at 400 feet, descending 575 feet in one mile, but cutting no gorge.

North of the *Barbon* Brook infall, numerous feeders flow off Middleton Fell, which is terminated above Middleton by the gorge of the River *Dee*. From Black Burton to Middleton the Ingleton Branch Railway contours the left bank of the *LUNE* at about 325 feet. The watershed between the *Dee* and the *LUNE* forms the county boundary of Westmoreland and Yorkshire, to within a mile of the infall of the *Rawthey*, after which it follows that river to the *LUNE*, and

then ascends the latter to a mile and a half below Low Barrow Bridge, where it trends east, and makes the watershed of Langdale Fell and the Calf.

River Rawthey.

This stream rises on Baugh Fell, 2216 feet, and Ravenstonedale Common, Westmoreland, west of Mallerstane, and flows in Yorkshire, and, with its tributaries, flows through Gorsdale and Dentdale. The *Dee*, 9 miles in length, drains the north-western corner of Yorkshire. On the right bank is Sedbergh, 400 feet above the sea, a mile below the infall of the River *Dee*.

Following the left bank of the *LUNE* valley from the infall of the *Rawthey* towards the source, it continues its northerly direction by Low Barrow Bridge as far as Tebay, where it turns eastward towards the village of Ravenstonedale, 800 feet above the sea, the watershed being 840; its head waters being chiefly fed by streams from the south flowing off Langdale Fell.

On the right bank of *Sanwith Beck* feeding the *LUNE*, descending the stream, are Newbiggen, Wath, where it becomes the *LUNE*, Kelleth, Rayne, and Orton. *Chapel* Brook, flowing past the latter, falls into the *LUNE* near Tebay, at 600 feet above the mean sea-level. The river is here about 36 miles from its outfall, which gives an average fall of about 16 feet per mile.

Another feeder, *Wasdale* Brook, rises near Wasdale Head; flows first to the north-east, and then, at Birkbeck, south-east to Tebay, the London and North-Western Railway here running along its left bank. The south part of Shap Fells, the Birkbeck Fells, and the north of Grayrigg Forest are drained by *Barrow* Brook, the infall of which is at Barrow Bridge, about 575 feet above the sea. Southwards from this point, the right bank of the *LUNE* is of small extent, the *KENT* watershed hugging the line of the river. The main line of the railway leaves the valley of the *LUNE* about 3 miles south of the Bridge at Low Gill Junction, and

crosses into the basin of the *KENT*. The *LUNE* descends to the 250-feet contour at Markthwaite Bridge, to 280 feet at Holm House, and 150 at Kirkby Lonsdale.

Kirkby Lonsdale.—*Acres*, 3250; population, 1733; rateable value, 430*l*. 12*s*. 6*d*.; constant supply from springs; reservoirs constructing under Public Health Act, 1875.

Above Whittington the 250-feet contour crosses into the next basin drained by the *Keer*, which rises in a col valley near Docker, at about 175 feet, the *Beckthwaite* rising in the same col, but flowing into the *LUNE* above Arkholme, between the watershed and the river, which run parallel to each other. At a distance of about 1½ mile are the villages of Gressingham, Hawkshead, Halton, Skerton, Ovangle, Overton, and Middleton, the watershed ranging through mosses south of Heysham and around Torrisholme.

RIVER KENT (*XXXIII.*).

Length of this river, 23 miles; area, 255 square miles, of which about 188 consist of rocks of Silurian age, 67 of Carboniferous Limestone. In this basin the Ordnance Survey include (1.) the small streams draining the Heysham peninsula as far as Hest Bank, where the Boulder Clay forms the sea cliff, and many large boulders are scattered on the beach. Westwards a peaty tract intervenes between this low undulating land and the Heysham Carboniferous Grit, which forms a cliff at Heysham Point, masked to the north towards the town of Morecambe by Boulder Clay.

Poulton Bare and Torrisholme.—Population, 3005; from Lancaster Corporation; average supply, 114,000; minimum, 100,000; maximum, 300,000 (constant); rateable value, 24,349*l*. 10*s*.; Local Government Act, 1858.

(2.) Streams draining into Morecambe Bay from Hest Bank to Bolton-le-Sands. The drainage here is obstructed, flat areas covered with peat mosses occurring, here and there interspersed by mounds or ridges of sand and gravel. Long ago these were believed by Dr. Buckland to be old glacier moraines, but they are certainly of marine origin; but

whether they belong to the Sands of the Middle Drift period, or to the later "Eskers," appears to be somewhat doubtful. They probably belong to the Gravels, containing large masses of scratched Mountain Limestone, occurring in the railway cutting at Carnforth.

(3.) The *River Keer*, draining the south side of Hutton-Roof Cray, Priest Hutton, Borwick, Carnforth, and Warton, west of which is Warton Cray, with its ancient Beacon, rising to 500 feet above the sea. West of this hill is a depression, at the bottom of which is Silverdale Moss, through which the Ulverstone Railway is carried, crossing the watershed of the *KENT* proper at 28 feet, from which it ascends to the top of Middlebarrow, 257 feet, and Arnside Knott, 522 feet, descending to the sea at Milnthorpe Sands.

The estuary of the *KENT* extends from Milnthorpe Sands to Halforth, a distance of 5½ miles, with a width at the entrance of three-quarters of a mile, winding further inland 1¼ mile, contracting at Dallam Tower to half a mile. A little north of the point where the sands are crossed by the railway, *Leigh* Brook drains Holme, Burton in Kendal; much of the tract is covered with peat-moss. Further north at Dallam Tower is the infall of the River *Beetha*. Ascending the stream on the left bank is the village of Beetham. Further east it receives *Peasey* Brook, rising near the *LUNE* watershed. The latter has an important tributary, *Lupton* Brook, flowing through the gorge between Scout Hill, 933 feet, and Farleton Fell, 800 feet, and rising in a col valley connected with the *LUNE*. On the right bank of *Peasey Beck* are the Powder Works, at 250 feet, Crooklands, and Milton; on the left bank of the *Beetha*, Deepthwaite and Stainton. Higher up the stream divides into two streams, *Saint Sunday Beck* and *Beehive Beck*. The right bank of this stream is limited in extent, the watershed between it and the *KENT* running close to it, by Woodhouse, Heversham, and Milnthorpe.

Following the *left* bank of the River *KENT* up stream, by Sedgwick, Natland, and Oxenholme Junction, and the east

side of Kendal, which is situated on the left bank of the river, about a mile north of the town, trends to the north-west, and receives a tributary, the River *Mint*, from the north-east, at an elevation of about 150 feet. Following the left bank of the latter, it receives a feeder at 350 feet, rising in Grayrigg Forest at 1300 feet above the sea. From the Forest the *KENT* watershed trends north-west over the tops of Whinfell Common, 1515 feet, Bannisdale Fell, 1737 feet, Tarn Cray, 2176 feet, Adam Seat, 2180 feet, and Lingmell End, 2183 feet. Parallel with this ridge on the *LUNE* side runs *Borow Beck*, and on the *KENT* side *Bannisdale Beck*, the River *Sprerit* flowing through Long Sleddale. The former rises at 1600 feet, and falls into the right bank of the *Mint;* the latter rises at 2400 feet, under the Knowe, and falls into the left bank of the *KENT* at Burnside, at 175 feet.

From Burnside to Staveley, small feeders drain the slopes of Potter's Fell, the most important rising on Green Quarter at 1250 feet, flowing through Skeggles Water at 1017, over Staveley Head Fell, and falling into the *KENT* at 300 feet. Three and a half miles further up the *KENT*, at Kentmere, it has risen to 600 feet, or 171 feet per mile. Two and a half miles further north, the stream is impounded, and forms Kentmere reservoir, with a top water of 973 feet, with feeders rising on the crags above or about 2000 feet above the sea. The northern watershed of the *KENT*, from Harop Pike to High Street, a distance of about 5 miles, is formed by a portion of the central east and west watershed. The western margin of this basin ranges south from High Street by the sharp ridge formed by Froswick, 2539 feet, Ill Bell, 2476, the Sallows, 1691, separating Troutbeck from Kentmere valleys, descending to 465 feet, in the col through which the Windermere branch railway is carried, which crosses the watershed about a mile and a half east of Windermere Station. Southward the watershed runs parallel to the Lake Windermere, and within a mile of it.

Following the *KENT* from its source, the first feeder

of importance is the River *Gowan*, falling in at Staveley. Between it and Kendal no stream of importance falls into the *KENT*, nor are there any between it and Beethwaite Green, 100 to 140 feet above the sea.

KENDAL.—*Acres*, 2622; population, 13,696; rateable value, 46,203*l.*; constant supply of 300,000 gallons from two reservoirs impounding streams, supplemented by pumping from a well; under Kendal Union Gas and Water Company Act, 1846 (9 & 10 Vict. c. 116).

Messrs. Hassard and Hemans, in calculating the periods of drought to be expected in the Lake District, quote the observations of Mr. Samuel Marshall of Kendal, taken for forty-four years from 1822, during which the longest drought occurred in the spring of 1852, which was, curiously enough, the wettest year of the period. From 19th February to 29th April (70 days) but 0·21 inch of rain fell, and all on three days.

The next drought approaching this in duration was from 1st April, 1861, to 8th of June (69 days), rain falling on nine days to the amount of 1·65 inch. In 1839, from 28th March to 4th June (67 days), rain fell to the extent of 1·97 inch on 12 days. In 1826, out of 60 days (28th April to 28th June), only 1·12 inch of rain fell on eight days. In 1829, in the 55 days from 14th December to 8th February, 1830, only 0·65 fell in five days. In 1844, 1853, 1864, 1865, droughts of shorter duration occurred.

River Gilpin.

Below Beethwaite Green, the *KENT* receives the River *Gilpin*, draining a low flat alluvial tract intervening between Whitebarrow, 706 feet, and Helsington Barrow, 600 feet. At the foot of the latter flows a tributary, *Underbarrow Pool*, draining Brigster, Underbarrow, rising above Crook, at 400 feet. The *Gilpin* rises east of Bowness, at 500 feet, descending to 100 feet at Churchtown, and to 25 feet east of Row.

From the infall of the *Gilpin* the low peat-covered tract occupies a large tract in Beetham, by Upta, and Meathop,

west of which is the infall of the River *Winster*, draining the valley between Whitebarrow and Ravensbarrow, 750 feet, rising at Brant Fell, near Bowness, at 500 feet, west of the source of the *Gilpin*, and flowing past Winster and Lindale to the estuary of the *KENT* at Blawith Point. Its low-water channel flows between this point and Holme Inland, past Grange, and then turning eastward falls into the channel of the *KENT*, near the point where the latter is crossed by the path across the "Sands."

The basin of the Upper *KENT* consists of consolidated ashes of the "Volcanic series," believed to be of Llandilo age, and called by Professor Sedgwick the "Green Slate and Porphyries," with a general west-south-west and east-north-east strike. When they approach the Shap Granite, they alter into a dark porcelaneous rock. The Granite is well known from the large oblong crystals of flesh-coloured orthoclase felspar, causing it to be largely used for ornamental purposes. Resting unconformably on the Volcanic series is the Coniston Limestone series, which is more or less earthy, fossiliferous, and associated with shales. It is on the same horizon as the Bala Limestone of Wales.

East of Kentmere, it is split up by ash-beds and shales, and is unimportant. It is overlaid by the Stockdale shales forming the base of the Upper Silurian. At the base are black shales, with graptolites above. They are pale-coloured, and are the equivalent of the Tarannon Shale of North Wales. They form b^6 of the Geological Survey Maps. Over them are the Coniston Flags and Grits, which are on the horizon of the Denbighshire Grits and Flags of North Wales. To the west of the *LUNE* Basin there are three Sandstone beds, but they thin eastwards, the lower and middle beds disappearing. The Flags, when cleavage and bedding happen to coincide, are useful. They reach a thickness, according to Mr. W. T. Aveline, of 6800 feet, striking with the older formation east-north-east across country. A second tract also occurs, brought in by a broad anticlinal, at the tops of Whinfell Beacon, Grayrigg Common, and Langdale Fells, in the *LUNE* Basin.

Over these rocks are the "Bannisdale Slates," which are roughly correlated with the Welsh Wenlock Shale and Lower Ludlow. The thickness, according to Mr. Aveline, is 5200 feet. The quarries with roughly cleaved slate that give the name are low in the series, and were first described by Professor Sedgwick.

Still higher in the series are the Hay Fell and Kirkby Moor Flags, the equivalent of the Upper Ludlow. They occur below the Carboniferous Limestone of Scarfoot and Barrowfield, west of Kendal; and from Kendal, by Docker Fell and Benson Knot, towards the *LUNE* valley. East of that river they do not occur.

The Upper Old Red Conglomerate is a local shore deposit, forming the base of the Carboniferous Limestone, and rests unconformably on the Silurians. It is well seen north and west of Kendal, and about Grayrigg. The fragments are all local, sometimes round, sometimes angular.

The area of Milnthorpe registration sub-district is 37,528 acres, with a population of 6622.

RIVER LEVEN (XXX.).

Length, 7 miles; area, 202 square miles, of which 190 square miles consist of Silurians, 10 of Carboniferous Limestone, and 2 of Permian Sandstone.

This basin is 20 miles long by about 9 miles in width; in shape rectangular. Its eastern watershed separates its waters from those of the *KENT*. Its northern margin is part of the east and west watershed, separating the *EDEN* and *DERWENT* Basins from the *LEVEN* Basin, the western watershed of which separates it from the basins of *DUDDON* and *Dalton-in-Furness* streams.

The Ordnance Survey includes in this basin the small stream draining the Cartmel valley, the Limestone district of Grange terminating to the north by a north-west fault ranging to Newby Bridge. To the west it thins out on the Bannisdale Slates, along a line ranging from Cark to Cartmel. The former place is on the St. Bees Red Sand-

stone of Permian age, extending to Flockburgh, where it rests on the Carboniferous Limestone. Between Holker and Ulverstone the *LEVEN* occupies a broad flat valley, in which are mounds and patches of Carboniferous Limestone.

Following the left bank of the *LEVEN* from its mouth, Windermere Lake is reached; it is $10\frac{5}{8}$ miles in length, and lies in a valley excavated by the agency of running water; but the portion of the valley concealed by the waters of the lake is a rock basin, excavated below the level of the outfall of the lake at Newby Bridge, and due to the erosive action of glaciers during the Glacial period. The deepest part of the lake I found by sounding to be opposite Wray Castle, on the western shore, where a depth of 39 fathoms, or 234 feet, was obtained, a depth greater than the English Channel between Folkestone and Boulogne. The top water-level of the lake is 134 feet, so that the bottom is 100 feet below the mean level of the sea. The level of the foot of the lake is 0·2 foot below that of the head.

Analysis of Windermere, made by the Rivers Pollution Commission, gave 5·78 of total solid impurity; 0·299 of organic carbon; 0·99 of chlorine; 4·0 of hardness, of which 2·4 was permanent.

WINDERMERE.—*Acres*, 200; population, 1269; rateable value, 4828*l.*; constant supply from reservoir of *Windermere District Water Company.*

BOWNESS.—*Acres*, 995; population, 1855; rateable value, 8993*l.*; from *Windermere Water Company.*

The following ANALYSES are given by the RIVERS POLLUTION COMMISSION.

	Total Solid Impurity.	Chlorine.	Hardness.		Total.
			Temp.	Perm.	
Rydal Lake	4·44	0·69	0·7	2·4	3·1
Grasmere	4·18	0·79	0·0	2·7	2·7
Upper Rothay	3·06	0·59	0·0	1·3	1·3

River Rothay.

North of Windermere is a tract of alluvial land which has been formed by materials brought in by streams silting up the lake. Across this tract flows the *Rothay*. On its left bank is the town of Ambleside, which is crossed by Stock Ghyl, forming the well-known waterfall behind the town. A few yards higher up the river is the infall of *Scandale Beck*. It is impounded in a small reservoir for the supply of the town. The direction of the valley is northward to the infall of *Rydal* Brook, draining the deep valley at the back of Rydal Park, where are the Upper and Lower Rydal Falls. At Thrang, the *Rothay* Valley turns westwards under Nab Scar, the Rydal Valley continuing the former north and south trend. At the foot of Nab Scar is Rydal Lake, 181 feet above the sea, and still higher up the valley is the larger lake Grasmere, 208 feet above the sea, and 180 feet in depth. Both these lakes are true rock basins, and the rock at the lower lip is glaciated, rounded, and smoothed.

Above Grasmere the east and west central watershed descends to 853 feet at Dunmail Raise, a col valley crossed by the coach road. The pipes of the *Manchester Corporation Water Supply* from Thirlmere will pass along the east side of the valley, through Nab Scar and Rydal Park, and above Ambleside. Following the right bank of the stream, an important feeder draining Easdale Tarn, 915 feet, comes down above Grasmere, and other feeders drain the steep sides of Silver Howe, 1345 feet, and Loughrigg, 1101 feet.

Ambleside registration sub-district contains 61,977 acres, with a population of 10,442 in 1881.

River Brathay.

On the right bank of the stream, near its outfall in the lake, is the River *Brathay*, flowing in from the west. Following its left bank is the village of Clappersgate, under the steep cliffs of Loughrigg, consisting of more or less altered volcanic ashes. At Skelwith Bridge a feeder

draining the picturesque lake, Loughrigg Tarn, 368 feet, comes in. Above the bridge the river is cutting a gorge through hard beds of the Volcanic Series, and forms Skelwith Force. Above it is Elter Water Lake, 187 feet above the sea, which receives on its southern shore the River *Brathay*, and on its northern *Great Langdale Beck*. On its left bank is Elter Water Village and the Powder Works, between which and Chapel Stile are well-glaciated mounds of rock. Higher up the stream the well-known Langdale Pikes tower above the valley, Harrison Stickle reaching 2401 feet, and Pike of Stickle 2325 feet. East of the former under Pavey Ark is Stickle Tarn, 1540 feet, and between the Pikes rises *Dungeon Gill*. West of the Pikes a number of feeders rise in the magnificent amphitheatre of rocks, the centre of which is Rossett Crag. The south side of the valley is formed by the hill called the Band, 1860 feet. Between it and Pike of Blisco is the deep valley of Langdale, whose southern feeder rises in Red Tarn, named from the redness, due to red oxide, of iron veins.

The *Oxendale* stream joins *Rossett Gill*, and becomes *Great Langdale Beck* at Wall End, a farm at the entrance of the col valley connecting Great with Little Langdale. The summit-level is a little over 700 feet; in it is Blea Tarn at 612 feet. East of the col, between the two Langdales, is Lingmoor Fell, 1410 feet, which is glaciated up to the top. Following the left bank of Little Langdale, a gorge is being cut back at Colwith Force. Higher up is an alluvial plain, representing a filled-up lake, of which Langdale Tarn, 340 feet is the remnant. From this lake to the source of the stream it falls 900 feet in less than two miles, or more than 450 feet per mile. From the Tarn to Windermere is a distance of 5¼ miles, with 206 feet of fall, or about 40 feet per mile. Immediately above the Tarn is the infall of *Greenburn Beck*, rising at 2200 feet above the sea, in the deep recesses of the Wild Valley lying at the foot of High Carrs, under the flank of Wetherlam; this stream falls 2000 feet in 3 miles, or 666 feet per mile.

The minor watershed dividing the waters of the *Crake* from the *LEVEN* ranges from High Carrs, through Wetherlam, north-east to Low Fell, then across the Tilberthwaite col valley, over Oxen Fells, across the col valley through which the coach road between Coniston and Skelwith is carried, over Arnside and Black Fell, 1056 feet. Thence it turns abruptly southwards, passing west of Hawkshead, ranges parallel to Coniston Lake, over Coniston Moor, the long slope to the east draining into the smaller tributaries of the *LEVEN*.

From the infall of the *Greenburn* to Windermere no stream of importance falls into the right bank. Here and there the rock in the valley is concealed by Glacial Drift, large scratched and smoothed boulders occurring in gravelly clay.

Following the right bank of the lake, glaciated rock mounds occur in Brathay Park; and at Pull Wyke Bay is the outcrop of the Coniston Limestone, striking south-west to the foot of Black Fell, where it is cut off by a fault bringing up the older Volcanic Series. On the south side of the bay is a stream draining Blelham Tarn, 138 feet above the sea. To the south the larger lake Esthwaite Water, near Hawkshead, a mile and a half in length, 80 feet in depth, and 217 feet above the sea, drains into the lower part of Windermere, below Near and Far Sawrey. West of this valley is Hawkshead Moor, and between it and Coniston Moor is *Grizedale Beck*, draining that village and Salterthwaite.

The southern continuation of the Windermere valley extends beyond the foot of the lake, and the flat tract is connected by a col with the valley drained by *Ayside Pool*, flowing through Cartmel to the sea at Cask. This probably was the line of flow of the united Windermere glaciers. The river at its present outfall trends south-west, and flows through the valley between Yew Barrow and Backbarrow, terminating in a north and south valley drained by *Rusland Pool*, falling into the *LEVEN*, west of Haverthwaite, draining Thwaite Head, Rusland and Bouth. West of

the latter plain is *Colton* Brook, draining the Furness Fells, and falling in at Legbarrow Point.

River Crake.

West of these two central streams is the River *Crake*, draining the Coniston Valley area. Following the left bank to the foot of Coniston Lake, it flows through a north-north-west valley cut through Fells of Upper Silurian Grits and Flags, ranging up to 600 feet in height, rising to 748 feet above High Nithwaite at the foot of the lake.

Coniston Lake is 6 miles long, with an average width of two-fifths of a mile; its height is 147 feet above the mean sea-level, or 13 feet above the surface of Windermere; its depth is 160 feet. Its eastern slope is steep and abrupt, but only rises to 900 feet, or about 750 above the lake. The principal feeder is the *Yewdale Beck*, which falls in on the right bank about half a mile from the head of the lake. At High Yewdale the stream divides, the eastern feeder draining the Oxen Fells col valley, the western feeder Tilberthwaite Valley, which is a very narrow gorge, being 850 feet deep between Yewdale Fells and Holme. Its western feeders rise under Wetherlam, its eastern drain the peat-covered col valley, connecting Yewdale and Little Langdale. A little below the infall of *Yewdale Beck* is that of *Church Beck*, draining Levers Water, 1350 feet, the Coniston Copper Mines, and Coniston Village. Its waters are milky from the Mines.

Following the right bank of the lake, no stream of importance comes in until the *Torver* stream falls in, rising at the back of Coniston Old Man, which rises to a height of 2633 feet. It flows through Goats Water, 1646 feet, and at Torver receives *Ash Gill Beck*, rising on the eastern slope of Walna Scar. At the foot of the lake, at Low Water End, 150 feet, the river flows out, continuing the south-south-east direction of the foot of the lake. To the south are a group of fells, 1000 feet in height, drained by streams flowing north-east into the *Crake*. On the right bank lower down is Spark Bridge, Penny Bridge, and Greenodd, where the river falls

into the tidal *LEVEN*. Below this point the river widens out, the channel hugging the left bank. The interval between it and the right bank is occupied by Greenodd Sands, into which flows *Newland Beck*.

On the hills west of Ulverstone rises *Levey* Brook, reaching the *LEVEN* estuary between Hummerside Point and Conishead Bank. North of its infall is that of the Ulverstone Canal.

Ulverstone. — Population, 9197; rateable value, 48,867*l*. 15*s*.; constant supply of 275,000 gallons, including trade supply, 600,000 gallons could be supplied by agreement as to priority from Barrow Corporation reservoirs at *Pennington Beck*, rising in Kirkby Moorside; under Ulverstone Waterworks Act, 1852, Barrow-in-Furness Corporation Water Act, 1873, and the Ulverstone Local Board Act, 1874.

The coast-line of the *LEVEN* basin terminates between Bardsea and Baycliff, the watershed ranging north of Great Urswick.

Census of 1881.

Registration Sub-districts.	Acres.	Population.
Ulverstone	8,463	12,237
Dalton	17,097	15,789
West Broughton	29,453	3,224
Hawkshead	33,570	3,371

O.S. CATCHMENT BASIN XXXII.

Area, 56 square miles, of which 26 consist of Silurians, 22 of Carboniferous and Yoredale Limestones and Shale, and 8 of Permian Sandstone. This basin has an extensive coast-line for its size, commencing near Baycliff, and trending south-west by Aldingham, the larger part of which parish has been washed away, Newbiggen, where a stream comes in from

Gleaston Castle, *Roose Beck*, to Rampside, thence north-west to Roose, and west to Barrow-in-Furness, then north by Cocken, Ormsgill, to the estuary of the *DUDDON*.

Between Haverigg Point and Walney Island, a distance of $3\frac{1}{2}$ miles, are Duddon Sands, extending out seawards in a convex curve, broken in the centre by the channels of the *DUDDON*, which unite near the Middle Buoy, where they are joined by the Scarth Channel, flowing in from the northern end of Walney Island, and draining at low tide the sand-banks between that island and the mainland, as far as Palace Nook, east of which these sands drain at low tide in the opposite direction, flowing into Walney Channel, which, after receiving the Barrow Channel, flowing between the Isle of Barrow and the mainland, becomes Peel Channel, which from Roe Island (attached to which is Peel Pier) turns south, and flows past the south-east corner of Walney Island, and passes over Peel Bar to the open sea.

Walney Island, west of this channel, is 8 miles in length. Its direction is south 30 east. Its western coast is straight, and covered with Sand Dunes rising to 50 feet above the sea. The eastern margin is deeply indented. On it are the villages of North Walney, North Scale, Biggar, and South Scale. Under the sand, and underlying Boulder Clay, is the St. Bees Sandstone.

At Ulverstone the Carboniferous Limestone rests on the Coniston Grits, Stockdale Shales, Coniston Slates, and Limestone, resting on Skiddaw Slates south of Ireleth, and on the Volcanic series north of that place. The Limestone extends from Bardsea, through Great Creswick, Dalton-in-Furness, extending to Duddon Sands. A west-north-west fault brings in the Permian south of the latter place, extending by Hawcoat, Ormsgill, Barrow, and Furness Abbey, where the north and south fault brings in the Yoredale rocks, extending from Newton, Gleaston, and Aldingham, south of which the Furness Abbey fault brings in the Permian, to the south at Roosebeck, Rampside, and Barrow.

The watershed ranges through Hawcoat, 270 feet, thence

by Ireleth, crosses the Lower Silurians, and ranges across Gunson, Height, and Woodland.

Barrow-in-Furness.—Population, 47,111; supply varies from 750,000 to 3,000,000 gallons (constant), from two impounding reservoirs holding 200 million gallons of water from Silurian wells; four distributing reservoirs and a high-service filtering reservoir constructing; rateable value, 167,371*l.*; under Barrow-in-Furness Corporation Acts, 1868 and 1872. Rainfall at 60 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
36·29	54·20	33·78	36·73	30·65

Average of 8 years, 37·08 inches.

Barrow-in-Furness: area in acres of registration sub-district, 9720; population, 47,276.

Dalton-in-Furness.—*Acres*, 7908; population, 13,350; constant supply of 150,000 gallons from reservoir collecting mountain stream.

RIVER DUDDON (XXIX.).

Length, 10 miles; area, 46 square miles, of which all consist of Silurian and Granitic rocks.

The estuary of the *DUDDON*, on either side of the Sands, is fringed by a low alluvial and peaty tract, into which falls on the left bank *Kirkby Pool*, west of which is a low ridge of Coniston Grits, on which is Broughton-in-Furness. The ridge is taken as the *DUDDON* watershed. West of this tract, at the head of the estuary, is the River *Sickle*, which nearly corresponds with the boundary of the underlying rocks of the Volcanic series at Dunnerdale Fells.

The *Sickle* rises at Caw Moss, 1750 feet above the sea, on the southern slope of Walney Scar. Following the left bank of the *DUDDON*, it receives at Seathwaite a feeder draining the Seathwaite Tarn, 1210 feet above the sea. It rises in Wrynose, near the Three Shires Stones, in the high col lying between Pike of Blisco and High Carrs. The western water-

shed ranges through Yew Bank, Harter Fell, 2140 feet, Ulpha Fells, Woodend, and Burn Moor.

O.S. CATCHMENT BASIN XXXI.

Area, 28 square miles, of which 18 consist of Silurians, 7 of Carboniferous Limestone, and 3 of Permian Sandstone.

This basin is chiefly drained by *Whicham* Brook, draining the eastern slope of the Black Comb ridge; from Chappels to near Silecroft it flows south-west, but does not flow on through the sandhills to the sea, but turns east-south-east, and flows on the sandy area, by Kirksanton, to the *DUDDON* estuary at Haverigg. To the east another stream rises in Millom Park at about 500 feet, and flows by Holborn Hill to the estuary at Borwickrails Harbour. East of the infall of this stream is the watershed separating this basin from that of the *DUDDON*, which runs parallel to *Black Beck*, a tributary of the *DUDDON* estuary, and within the basin of that river.

To the west of the estuary of the *DUDDON* is the mountain called Black Combe, 1960 feet, composed of Skiddaw Slate, striking with the ridge north-east, and faulted to the east and north against the Volcanic series, with the exception of one point at Fellside, at the north-west corner of the mountain, where the boundary is a natural one. To the west the Slates are overlaid unconformably by the St. Bees Sandstones, by Kirksanton, Whicham, and Whitbeck.

East of Holborn Hill, the Permian rests on the Carboniferous Limestone, worked for iron-ore at Hodbarrow Point.

RIVER ESK (XXVIII.).

Length, 9 miles; area, 64 square miles, of which 44 are Silurians, and 20 Permian Sandstone.

The southern margin of this basin is formed by the Black Combe ridge; descending by Black Crags, it crosses the Drift terrace at the base, fringed with Sand Dunes, between Whicham and Whitebeck. North of the latter place a stream comes down from western summit of Black Combe,

and north of it are several parallel streams draining Little and Bootle Fells.

The Rivers *ESK*, *MITE*, and *Irt* fall into the same estuary, the former stream being considered by the Ordnance Survey to form a distinct basin. To the south-east it is bounded by the Black Combe streams, to the north-east by the *DUDDON*, and for a short distance by the basins of the *LEVEN* and the *DERWENT*. This part of the watershed traverses some of the highest ground in England, trending north-west from Shelter Crags, 2631 feet, by Bow Fell, 2960, to Great End-then, 2490 feet, then south-west over Scaw Fell Pike, 3210 feet, Scaw Fell, 3162, and thence by Eskdale Fells to the sea. *Linbeck Gill*, draining Devoke Water 766, falls into the left bank at Linbeck, 75 feet above the sea. On the right bank, *Whittle Beck* drains Burnmoor Tarn, 832 feet, and falls into the *ESK* at Bort, at about 130 feet.

On the right bank of the *ESK*, near its mouth, is Muncaster Castle and St. Michael's Church, on a prominence rising to 373 feet.

Muncaster registration sub-district contains 44,087 acres, with a population of 2655.

Bootle registration sub-district contains 47,214 acres, with a population of 9569.

RIVER MITE (XXVII.).

Length, 14 miles; area, 61 square miles, of which 52 consist of Silurian rocks, and 9 of Permian Sandstone.

The eastern boundary of the River *MITE* ranges from Ravenglass through Muncaster Fell. Its western boundary, or minor watershed, is formed by the Ill Gill Head ridge, 1978 feet, forming the top of Wastwater Screes. The stream rises 900 feet above the sea, on Eskdale Moor.

River Irt.

Trending eastwards, this river takes off the surplus waters of Wastwater Lake. Their surface is 204 feet, the cliffs on the left bank forming the well-known Wasdale Screes.

Wastwater is 204 feet above the mean sea-level, 3 miles in length, and 270 feet in depth. At the head of the lake is an alluvial tract, into which enters *Lingmell Beck*, and other mountain streams. At the foot of the lake is the village of Strands, and below it is the infall of the River *Bleng*, at 75 feet.

Below the infall of *Bleng*, on the right bank of the *Irt*, are the villages of Hall Santon, Holmrook, and Drigg. At this place the river does not continue its south-west course through the Sand Dunes of Drigg Common, but turns south-east and flows south-east to the channel of the Rivers *ESK* and *MITE*, which cuts off the southern prolongation of the Sand Dunes at Drigg Point.

RIVER CALDER (XXVI.).

Length, 6 miles; area, 28 square miles, of which 12 consist of Silurians, 3 of Carboniferous rocks, and 13 of Permian Sandstone.

The eastern watershed commences on the sea-coast at Carl Crag, crossing the Sand Dunes at Low Moor, rises to 61 feet, ranges a little east of north through the Drift-covered Permians of Drigg Cross, to Gosforth, 338 feet, thence north-east to Swainson Knott, 1056, where it trends east by Stockdale Moor.

Two independent small streams are included in this basin. The first drains the country near the *ESK* watershed, and falls into the sea at Leaside. The next has a longer course; rising near Ponsonby, it flows by Calder to the sea at Seascale How, half a mile south of the outfall of the *CALDER*. The first tributary of importance on the left bank of the stream is *Warm Gill*. On the right bank is Calder Bridge, 176 feet above the sea, and Sellafield, near the outfall, 67 feet.

RIVER EHEN (XXV.).

Length, 10 miles; area, 72 square miles, of which 44 are Silurians, 3 Carboniferous Limestone, 3 Carboniferous rocks, and 22 of Permian Sandstone.

In this basin is included the whole of the area bounded by the coast-line, extending from Sellafield to the north of Whitehaven, in the centre of which is the promontory of St. Bees Head, formed of the Permian Red Sandstone, named after the Head, the St. Bees Sandstone.

The *EHEN* rises near the sea-coast, and flows south to Braystones. Were its valley depressed beneath the sea, the district around St. Bees Head would form a triangular-shaped island. At Braystones it receives a stream draining Hale, and St. John and St. Bridget Beckermet. The valley is cut through Boulder Clay, resting on the St. Bees Sandstone. The united stream has not a channel through the Boulder Clay direct to the sea at Braystones, but turns to the south-east, and flows for 2½ miles parallel to the coast, falling into the channel of the *CALDER*. This deflection of the West Cumberland rivers outfall is due to the silting up of the flow-tide side of the stream, which here is the north side of the outfalls. The mouth of the *ESK* is the only stream not so deflected, but this is protected by Drigg Common Sand Dunes intervening between the sea and the *Irt*.

The country east of the Ehen Valley, consisting of the wild and deep valley of Ennerdale, is drained by the tributary River *Liza*, which rises under Green Gable, 2474 feet above the sea, and flows at the foot of the Pillar rock, 2827, on the south side, and of Scarf Gap on the north; thence through Ennerdale Lake to the *EHEN*, between Egremont and Cleator Moor. The lake is 2½ miles long, 368 feet above the sea, and 80 feet in depth.

Cleator Moor.—*Acres*, 814; population, 10,420; rateable value, 30,701*l.*; constant supply of 150,000 to 230,000 gallons from storage reservoirs, holding 4,500,000 gallons, collecting mountain streams; Public Health Acts, 1848, 1858.

The registration sub-district of Egremont contains 35,698 acres, with a population of 19,577. The registration sub-district of St. Bees contains 11,130 acres, with a population of 10,885.

These streams all terminate against an important watershed crossing England from east to west. In the Lake District to the south of it are the Lakes Ennerdale, Wastwater, Coniston, Esthwaite, and Windermere; to the north of it, Crummock Water, Buttermere, Bassenthwaite, and Derwentwater, in the basin of the *DERWENT*, and Ullswater and Haweswater in the basin of the *EDEN*. On this watershed are situated the chief passes of the Lake District —Scarf Gap, the Langdale passes, Dunmail Raise, and Kirkstone Pass; its eastern prolongation forms the boundary between the *EDEN* on the north, and the *KENT* and *LUNE* on the south, crossing the Pennine axis between the *EDEN* and the Yorkshire *OUSE*, and still further east between the *TEES* on the north and the Yorkshire *OUSE*, *DERWENT*, and *ESK* on the south.

The top-water level of Ennerdale is 369 feet, the breadth of the lake at the base is a little more than three-quarters of a mile, the effluent river takes the name of *EHEN*, receiving on its right bank *Crossdale Beck* at Ennerdale Bridge, at about 365 feet, *Lingla Brook*, draining Frizington, at 275 feet, and the River *Keekle* at 175 feet, the village of Cleator occurring in the angle of the two streams. The *Keekle* rises on Distington Moor, 3 miles from the sea, flows to the south, receiving *Dub Beck*, draining Arlecdon on its left bank, joins the *EHEN* at Cleator, which takes the direction of the tributary flowing south by Egremont to the sea.

The St. Bees Head area, lying between Whitehaven and St. Bees, is drained by small streams, flowing in opposite directions at the bottom of the low, flat-bottomed col valley, running from sea to sea, traversed by the railway to Whitehaven, which is crossed in the centre by the Central or "pass" watershed of the North of England. The Catchment Basin Map of the Ordnance Survey represents the watershed as running westward to the sea from Watch Hill, 565 feet high, and the map includes Whitehaven in the *EHEN* Basin, though it is on the outfall of a stream flowing north. From Watch Hill the watershed runs south by Yew Bank 738 feet; to

Richmond Hill, Hensingham, south of which it descends to about 60 feet, ascending to 309 feet at Sandwith, and terminating at St. Bees Head.

Population in 1871 in Cestrian and Lancastrian Group.

Counties.	Population.	Density.	Proportion in this Group.	Probable Population.
Flintshire	76,245	2·4	$\frac{9}{10}$	68,621
Merionethshire ..	47,369	7·3	$\frac{1}{3}$	15,787
Cheshire	561,131	1·2	All	561,131
Derbyshire	380,538	1·7	$\frac{1}{5}$	76,107
Lancashire	2,818,904	0·4	All	2,818,904
Yorkshire, W.R. ..	1,831,223	0·9	$\frac{1}{150}$	12,208
Westmoreland	65,005	7·4	$\frac{1}{2}$	32,502
Cumberland	220,245	4·5	$\frac{2}{11}$	40,088
Population in 1881.				
Flintshire	80,373	2·1	$\frac{9}{10}$	72,336
Merionethshire ..	54,793	7·0	$\frac{1}{3}$	18,264
Cheshire	643,237	1·1	All	643,237
Derbyshire	461,141	1·4	$\frac{1}{5}$	92,228
Lancashire	3,454,225	0·3	All	3,454,225
Yorkshire, W.R. ..	2,175,134	0·8	$\frac{1}{150}$	14,500
Westmoreland	64,184	7·7	$\frac{1}{2}$	32,092
Cumberland	250,630	3·4	$\frac{2}{11}$	45,568

CHAPTER XXXIV.

CUMBERLAND STREAMS NORTH OF THE CENTRAL WATERSHED.

O.S. CATCHMENT BASIN XVII.

Area about 17 * square miles, all of which are occupied by Coal Measures covered with Drift. This basin occupies a triangular area intervening between the *DERWENT* and *EHEN* Basins; it has a coast-line of 9 miles, its watershed commences at St. Bees Head at 323 feet, rising to 704 feet on the eastern angle of the area, descending to 129 feet at Chapel Hill immediately south of Workington. To the south a small stream drains the Hensingham and Whitehaven valley; another, Distington and Moresby; and a third flows out at Harrington.

Whitehaven.—*Acres*, 310; population, 19,321; rateable value, 50,074*l.*; constant supply of 900,000 gallons, by gravitation from Ennerdale Lake; 12 Vict. c. 17; 27 & 28 Vict. c. 121.

RIVER DERWENT (XVIII.).

This river is 31 miles in length; area, 262 square miles, of which 229 consist of Lower Silurian rocks, 11 of Carboniferous Limestone, and 22 of Carboniferous, the latter being chiefly Coal Measures.

The southern margin of this basin is formed by the central east and west watershed, commencing at Seat Sandal; it descends to Dunmail Raise, 774 feet, ascending to 1811 feet at Steel Fell, overhanging Wythburn, whence it ranges south-west to High White Stones 2500 feet, running along the peat-covered ridge separating Long Strath from the

* Six miles of this is included by the O.S. in the basin of the *EHEN*.

Great Langdale valley, by Rossett Pass to Bow Fell, 2500 feet, whence it trends northward to Great End, 2984 feet. The ridge between these two mountains, 1½ mile in length, is the central point of divergence of the watershed of five of the principal basins of the Lake District, a sixth basin (that of the Ennerdale valley) being included, by the continuation of the ridge 1½ mile further north-west to Great Gable, 2949 feet; lying under the trough of the high mountain pass, between the ridge and other crags, are Angle Tarn, Sparkling Tarn, and Styehead Tarn, drained by the head waters of the *DERWENT*.

From Great Gable by Green Gable (2474 feet), to Brandreth the watershed trends north, separating the *Liza* from the *DERWENT*. At Brandreth the northward direction is continued to Dale Head by the minor watershed separating the waters flowing into the Buttermere valley from those of Borrowdale. The central or "pass" watershed trends north-west following the strike, the Buttermere valley, by Scarth Gap to Gale Fell and Great Borrer, 2019 feet, and Gravel Fell, 1720 feet, forming the ridge between Ennerdale Lake and Crummock Water; thence it descends rapidly, and reaches the sea north of Whitehaven, overhanging the head waters of *EHEN* at a height of 565 feet.

Following the left bank of the *DERWENT* from its estuary at Workington, which is built on this bank, by Stamburn and Great Clifton, it receives the River *Marron*, rising on Knock Murton Fell, 1461 feet, to Lamplugh, thence by Branthwaite, Dean, and Little Clifton to the *DERWENT*. The Cleator and Egremont Railway follows the left bank of the *Marron*, crossing the "Pass Watershed" at Rowrah, at about 540 feet.

River Cocker.

This river is 12 miles in length; on its left bank, at the foot of the Fells, are the hamlets of Southwaite, Thackthwaite, and St. Bartholomew's; the latter place is situated in the angle between the foot of Crummock Water and the stream draining Lowes Water lake and valley, which is re-

markable for sloping in a direction contrary to the general drainage trend of the country, south-east instead of north-north-west. The lake was scooped out by a glacier occupying the valley between Carling Knott and Low Fell. Crummock Water is 2½ miles in length, 320 feet above the sea, and 132 feet in depth: it is separated by a little more than half a mile of alluvium from Buttermere lake 1¼ mile in length, receiving the drainage of Wernscale Bottom, and the stream flowing through the rocky gorge forming Honnister Pass; Buttermere is 330 feet above the sea. The secondary watershed separating this valley from the *DERWENT*, ranges parallel with it from Dale Head by Robinson, 2417 feet, and Lorton Fells. On the right bank of the alluvial flat, between the lakes, is the village of Buttermere. At Low Lorton, *Whit Brook* comes in, rising near Lord's Seat, (1811 feet), within a mile of Bassenthwaite lake.

Following the *DERWENT* from the infall of the Cocker, the stream rises to the foot of Bassenthwaite lake, which is 4 miles in length, 225 feet above the mean sea-level, and 68 feet deep, receiving at its head two streams, *Newland Beck* and the River *DERWENT*. The former stream is about 7 miles long, rising under Dale Head, and flows past Little Town, Stair, and Braithwaite, draining the vale of Newlands, a valley running parallel to Borrowdale, and separated from it by the Cat Bells range, rising to 1482 feet, forming the western margin of Derwentwater.

From the head of Bassenthwaite to the foot of Derwentwater is an alluvial flat tract, 2½ miles long, once part of the lake, and since filled up by *débris* brought down by streams, separating the lake into two portions. Following the left bank of Derwentwater to the head of the lake, two valleys are seen, the larger being drained by the *DERWENT*, and the smaller and eastern valley by *Watendlath Beck*. Derwentwater is nearly 3 miles long, is 238 feet above the sea, and 72 feet deep. On the left bank of the *DERWENT*, on the plains at the bottom of the valley, are the villages of Grange and Seattoller; at the latter place, *Horse Gill*, draining

the east side of Honnister Pass, has its outfall. The source of the *DERWENT* at Styehead Pass has already been referred to; on its right bank are the hamlets of Seathwaite, Thornythwaite, and Rosthwaite, where the infall of *Longstrath Beck* occurs.

Between this stream and its tributary, *Greenup Gill*, and the Thirlmere valley, are two ridges forming minor watersheds uniting at Ullscarf, 2370 feet; the western spur ranging by Green Comb, 1580 feet; and Brund Fell, 1383 feet, separates Longstrath from *Watendlath Beck*, which flows through Blea Tarn and Watendlath to the lake at Lodore, falling over rocks of the altered volcanic ashes, and forming the well-known Falls of Lodore. East of this valley is the watershed ranging through Armboth Fell, 1588 feet, Castlerigg Fell, 1932 feet, on which rises *Brackle Beck*, flowing past Castlerigg to the lake opposite Lord's Island.

River Greta.

Immediately below the foot of Derwentwater, the *DERWENT* receives the *Greta*, 9 miles in length, on the left bank of which the town of Keswick, and the suburb of Brigham, two powerful feeders, come in on the left bank, *Naddle Beck*, rising under the Pewits, west of the foot of Thirlmere, and flowing past Dale Bottom, and *St. John's Beck*, falling a mile higher up the stream; this Beck carries off the drainage of the Wythburn and Thirlmere Basin; it is bounded to the south by Steel Fell, Dunmail Raise, and Seat Sandal, to the east by the Helvellyn ridge, 3118 feet, and west by Armboth Fells, 1588 feet. At the head of the lake, on the right bank of Wythburn, is the hamlet, and "Wythburn's modest House of Prayer," 588 feet above the sea. At Green Dodd, 2804 feet, the watershed separating the *DERWENT* Basin from the streams flowing into Ulleswater trends to the north by Matterdale Common and Great Mell Fell. Thirlmere is 2¾ miles in length, 533 feet above the mean sea-level, and 108 feet in depth; it has a top-water area of 335 acres, which will be increased to 800 acres by the proposed embankment, 50 feet high, raising its surface,

sanctioned by Parliament for the supply of Manchester.* At first only 10,000,000 gallons will be drawn daily, and this will be gradually increased to 50,000,000 gallons. The compensation water given is very small, being only 5,500,000 gallons daily to be sent down *St. John's Beck*.

Above the infall of *St. John's Beck*, the *DERWENT* takes the name of *River Glenderamackin*, receiving *Mosedale* and *Trout* Becks, draining Matterdale Common, and following it near Wallthwaite.

The right bank of the valley is very steep, being bounded by Saddleback, 2847 feet, and Lowseat Fell, 2344 feet, separated by *Glenderaterra Beck* and Skiddaw. At the foot of the slope are the villages of Applethwaite and Millbeck, 403 feet.

Keswick.—*Acres*, 542; population, 3219; rateable value, 11,430*l*. Supply from streams on Skiddaw, on Lord Ormathwaite's land, impounded, constant, 70,000 gallons per day.

The Keswick registration sub-district contains 76,709 acres, with a population of 6935.

Workington.—*Acres*, 267; population, 13,305; rateable value, 19,098*l*. 9*s*. 3*d*. Constant supply of 400,000 gallons pumped from well into reservoir by two small engines, and partly from River *DERWENT*. Works purchased from Waterworks Company under Local Government Act, 1868, an inadequate scheme sanctioned by Parliament to obtain a supply by gravitation from Crummock Water for Cockermouth and Workington.

The Workington registration sub-district contains 19,944 acres, with a population of 20,840.

Cockermouth.—*Acres*, 2424; population, 5354; rateable value, 13,000*l*. Constant supply of 136,000 gallons pumped into reservoir from River *Cocker;* Public Health Act, 1848. Rainfall at Whin Fell Hall, 250 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
45·07	71·68	43·03	44·20	45·61

Average of twenty-five years, 53·11 inches.

* The aqueduct, 102 miles in length, will consist of 14 miles of tunnels, 39 miles of "cut and cover" channel, in the ground, and 33 miles of cast-iron syphon-pipes, and bridges.

The Cockermouth registration sub-district contains 51,721 acres, with a population of 10,965.

TABLE showing the AVERAGE RAINFALL in the ENGLISH LAKE DISTRICT, from OBSERVATIONS made by the late DR. MILLER, F.R.S., from 1844 to 1853.

Highest summit of the district 3000 feet above the sea, lowest 200 feet.

Place of Gauge.	Elevation above the sea.	No. of years' observations.	Mean rainfall.
Keswick	258	10	59·6
Loweswater	336	10	67·29
Crummock Lake	260	10	84·1
Gatesgarth	290	9	114·7
Eskdale Head	..	7	77·9
Wastdale Head	247	10	101·4
Selside	736	5	73·5
The Howe, Troutbeck	503	10	79·3
Ambleside	190	6	79·6
Seathwaite	..	9	140·5
Stonethwaite	340	7	111·4
Mean rainfall of the district ..	..	..	89·93

From a more extended table of Dr. Miller's, given in Beardmore's 'Hydrology,' a mean annual fall of 100·56 inches is deduced for the years 1847 to 1853 inclusive; for the latter year only, which was exceedingly dry, the mean fall was 80·60 inches.

The rainfalls of the highest points were as follows:—

	Elevation.	1848.	1849.	1850.	1851.	1852.	1853.	Total.	Mean.
The Pike	3166	94·70	83 20	80·30	71·30	81 30	56·20	467·00	77·83
Great Gable	2925	91·30	84·90	87·30	85·70	81·20	59·70	490 10	81·68
Sprinkling Tarn ..	1900	108·60	121·10	127·80	134·80	125·30	94·60	752·20	125·37
Brant Rigg..	924	109·20	87·30	91·10	89·50	98·20	73·40	548·70	91·45
Scattoller Common ..	1338	109·50	109·00	138·80	141·40	156·60	111·40	796·70	132·78
The Stye	948	..	..	174·30	169·60	167·70	124·90	636·50	159·12

The observations taken both in Wales and the Lake District mountains show a steady increase of the precipitation

of rain with elevation above the sea, but this does not go on indefinitely, for the maximum precipitation of all is not found on the highest summits but on the lee-side of hills, where the clouds, impelled by prevalent sea-winds (west-south-west to west-north-west), have been carried through mountain passes; as for example, at Stonethwaite, Seathwaite, little more than 300 feet above the sea, the fall is nearly double that of the Pike and Great Gable, averaging 3000 feet above the sea.

RIVER ELLEN (XVI.).

Length, 16 miles; area, 72 square miles, of which Lower Silurians occupy 6, Carboniferous Limestone 13, Carboniferous rocks 18, and 35 of Permian Sandstone.

Maryport.—Population, 8177; rateable value, 17,175*l.*; constant supply pumped from River *DERWENT* at Goat's Mill Race, into storage reservoir; Maryport Improvement and Harbour Act, 1866.

Maryport registration sub-district contains 21,781 acres, with a population of 18,050.

RIVER WAVER (XV.).

Length, 12 miles; area, 70 square miles, of which 12 consist of Carboniferous Limestone, 4 of Carboniferous rocks, 4 of Permian (St. Bees) Sandstone, and 49 of Upper Gypseous Permian Marls.

The outfall of the river unites with that of *WAMPOOL* in Morecambe, and then trends west by Skinburness and Silloth.

Off Beckfoot, low-water mark at Catherine Scar is more than a mile from the coast-line, but at Silloth Bay it approaches within a quarter of a mile of the coast; eastward both banks of the estuary are fringed with salt marshes, and the area between this river and the *WAMPOOL* is Widholme Flow, and other mosses; on the south side of the Moss is Kelsick and Abbey Town.

SILLOTH.—Rainfall :—

1878.	1879.	1880.
29·26	35·57	30·55

Average of twenty-six years was 34·01 inches.

RIVER WAMPOOL (XIV.).

Length, 14 miles; area, 78 square miles, of which 8 consist of Carboniferous, 61 consist of Permian (14 being St. Bees Sandstone, and the remaining 47 are Upper Gypseous Marls), 3 of Trias, and 6 of Lias.

The western watershed commences in the Newton Arlosh Mosses, crosses Widholme Flow, thence by Oulton Village, 101 feet, and Dockray, and south to the Caldew Valley, which it overhangs at 520 feet, then trending north the eastern watershed separates this basin from the *EDEN* Basin, by Great Orton, 221 feet, and Kirkbampton to Burgh Marshes, at Boustead Hill.

The general northerly direction of the stream ceases at its outfall, and instead of flowing out at Port Carlisle, across the low tract formed by Glasson Moss, it turns abruptly westerly, forming a trumpet-shaped estuary between Newton Arlosh and Anthorn; west of the latter place the coast-line trends north-east to Bowness and then south-east by Port Carlisle, Drumburgh, and Boustead Hill. The whole of this tract is low and peat-covered, and would be converted into an island by a 15 feet depression, the channel being between Drumburgh and Whitrigg. The western feeder is the River *Wiza*, the eastern is *Shalk* Beck, on which is Carthwaite.

WIGTON.—*Acres*, 775; population, 3600; rateable value, 11,887*l.*; constant supply of 40,000 gallons from reservoir in Red Dial, 1½ mile from town, storing water from a 'boiling spring' and the River *WAVER*. Works will be purchased from the Company by the Sanitary Authority.

Wigton registration sub-district contains 43,484 *acres*, with a population of 9124.

RIVER EDEN (*XIX.*).

Length, 69 miles; area, including its tributaries, 915 square miles, of which 135 are occupied by Silurians, 391 by Carboniferous Limestone, much split up by Sandstones and Shales, 357 by Permian rocks, chiefly of the Penrith division, 18 by Triassic (Kirklinton) Sandstone, and 12 by the Stanwix Marls, which are probably Keuper, and 10 by Lias.

From the watershed at Boustead Hill to Red Kirk Point, on the Scotch side of the Solway Firth, is $3\frac{1}{2}$ miles, measured from the railway and Roman VALLUM, for traversing the sands between the two points is not only the channel of the *EDEN*, but that of the *ESK*, the two uniting off Port Carlisle. The eastern watershed of the *EDEN* terminates at Wetheral and Rockcliff Marshes, from which to the Burgh Marshes, traversed by the watershed, is only $2\frac{3}{4}$ miles, representing the whole sea-frontage of this very large basin.

On the low grounds fringing the left bank of the river are Burgh-by-Sands, Beaumont, and Kirkandrews-upon-Eden; and above the 100-feet contour is Moorhouse and Bellevue. The top of the valley is higher on the left bank than on the right.

River Caldew.

Seven miles from the sea, at the bottom of the valley, is the infall of the River *Caldew*, 16 miles in length. Following its left bank, it receives, south of Dalston, *Gill Beck*, rising in the mosses on the *WAMPOOL* watershed, and draining Cardew. Its chief feeders rise on the hills 2300 feet above Bassenthwaite lake. On this stream are Dalton and Sibergham.

The City of CARLISLE is built in the angle between the *EDEN* and the *Caldew*. *Acres*, 1570; population, 35,866; rateable value, 112,982*l.*; constant supply of 1,134,600 gallons pumped from *EDEN;* purchased from *Carlisle Waterworks* under Public Health Act. Rainfall at Spittal Cemetery, 113 feet above the sea:—

1876.	1877.	1878.	1879.	1880.
31·70	44·68	29·68	26·19	29·33

The Carlisle registration district is divided as follows :—

Sub-Districts.	Acres.	Population.
Wetheral	16,202	4,033
St. Cuthbert	10,098	17,276
St. Mary	2,097	22,214
Stanwix	12,359	4,110
Burgh	9,647	1,360
Dalston	18,761	3,750

I have to thank my former colleague Mr. Holmes, F.G.S., for the following sequence of the Secondary and Permian rocks in the *Carlisle district*:—

1. Lias, limestones and shales (mistaken for coal), first determined by Mr. Brocklebank, of Ackton and Orton.

Trias.

2. Keuper (?) Marls, drift-covered, of Stanwix and West Linton, 50 to 100 feet. *Unconformity.*

3. Bunter Sandstones, red and white current-bedded soft sandstones, of Kirklinton and Rockcliffe. There is little doubt they are of Bunter age, as suggested by Professor Harkness, but they contain a band resembling the St. Bees Sandstone, 400 to 500 feet.

Permian.

4. Gypseous Shales, only found in borings 600 to 700 feet, cut off by a fault in the valley of the Calder.

5. St. Bees Sandstones, Red Sandstone of grey bed at the top, probably 1500 feet thick south-east of Carlisle, and resting on the Carboniferous rocks, north of that city.

6. Shaley Beds.

7. Penrith Sandstones, Red Sandstones not occurring north of the line bringing in the St. Bees Sandstones, but reappearing in Dumfriesshire.

The Stanwix Marls form an inlier extending from Carlisle, Stanwix, and Houghton, to Westlinton, on the south bank of the River *LINE*.

The older Kirklinton Sandstones occupy a larger area: their southerly extension is cut off by an E.S.E. fault, ranging south of Cummersdale; northward, at the mouth of the *EDEN*, these beds rest on upper Gypseous Marls; while still further north and east from the mouth of the *ESK*, by

Solway Moss, the River *Liddel*, and River *LINE*, it rests on the St. Bees Sandstone.*

River Petterill

Is 21 miles in length. The Preston and Carlisle Railway follows the left bank of the valley of the River *Petterill*, by Southwaite, Culthwaite, and Catterlen, east of which the valley trends westward, the railway crossing the stream at the bend of the town, from which the stream flows by Laithes, Greystoke, rising between Motherby and Penruddock, at about 875 feet. The source is close to the railway-station, but the railway here has not been carried down the valley, but eastward, through a cutting in Beacon Hill, so as to intercept the town of Penrith, which is drained by a stream flowing into the *Eamont*, but the valley in which this stream flows was probably continuous before the Glacial epoch with the valleys of the *Lowther* and *Eamont*, the junction of which is 3 miles to the south of the present *Petterill* watershed; the watershed separating the waters of the latter basin, and the Eden ranges north-north-west, halfway between the two streams by Lazonby Fell, 811, and Blazefell, 792 feet, Aiketgate, and Barrack Fell. The old coach road to the north is carried on along the right side of the valley of the Petterill, on the line of the still older Roman Road, by Plumpton Head, the Roman Station of VOREDA, and High and Low Hesket.

Between Armathwaite and Lazonby the *EDEN* flows through a narrow gorge, widening out between this place and Great Salkeld and Edenhall, south of which the valley is breached by the tributary valley of the *Eamont*, flowing at right angles to the course of the *EDEN*.

PENRITH.—*Acres*, 7587; population, 9268; rateable value, 24,389*l*. Supplied by water pumped from the *Eamont*, the

* Mr. T. V. Holmes, "On the Permian, Triassic, and Liassic Rocks of the Carlisle Basin," 'Quarterly Journal Geological Society,' 1881, p. 286, with map.

only outlet of Ulleswater Lake, raised by the water-power of the river up to 1862, in which year there was not water-power enough to turn the wheel, and a permanent steam-engine of 14-horse power has been fixed for short water seasons. The works are a mile from the town, and a flour-mill near the waterworks wheel has a right to half the water-power. Mr. John Taylor says that, in 1862, the water flowing from Ulleswater, with its gathering ground of about 54,500 acres, was reduced to 20,000,000 gallons per day for some months. The flow down the river on the 26th of May, 1868, was 120,000,000 gallons per day, being about an average flow, showing that, in dry seasons, the water is reduced to one-sixth its ordinary volume. The supply is constant: 230,000 gallons are used for domestic purposes, and 200,000 gallons for manufacturing purposes. Under Public Health Act, 1848, and Local Government Act, 1858.

River Eamont.

The drainage area of Ulleswater is given by Mr. Bateman, C.E., at 36,198 acres, or the same as that of Bala Lake: the actual area of the water of the lake is 2243 acres. Mr. Bateman was of opinion that if the present level of the lake, 470 feet above Ordnance Datum, were raised 5 feet, it could supply 50 million gallons a day, after 100 days' drought, and allowing for compensation.

Ulleswater is $7\frac{3}{4}$ miles in length, it is 476 feet above the mean sea-level, and is 210 feet in depth.

Several square miles on the left banks of Ulleswater are drained by *Cary Beck*, flowing past Downthwaitehead and Dockray, higher up the lake, in the infall of *Glencoin Beck;* and still further south is *Glenridding Beck*, draining the eastern recesses of Helvellyn. One feeder rises above Greenside Lead Mines, another above Keppel Cove Tarn, and a third in Red Tarn, separated from the former tarn by the sharp spur Cat-stye-Cam. At the foot of the lake a stream falls in, carrying the united waters flowing down Grisedale,

and rising above the Tarn under Seat Sandal, and then rising on Kirkstone Pass, and flowing through Brothers Water 520 feet, with feeders rising on High Street, which form the minor watershed between the *Eamont* and Ulleswater valley, and the *Lowther* and Haweswater valley. The watershed descends from High Raise, 2634 to 1832 feet, on Swarth Fell, falling into *Eamont* at the infall of the *Lowther* at 375 feet, between the foot of the lake and the point of the village of Pooley Bridge, Stockbridge, Yanwith, and Eamont Bridge.

River Lowther.

This river is 12 miles long. Following its left bank, by Askham, it receives *Heltondale* Beck, between Helton Fleeker and Butterweek, and *Haweswater* Beck at Bampton, at 575 feet; the stream flows out of Haweswater (694 feet), on its left bank flows in *Measand Beck*, forming a headland dividing the lake into two divisions, known as High Water and Low Water. At the head of the lake is an alluvial tract, marking its former extension, through which flows the stream, descending Wasdale and Blea Tarn, 1584 feet, under High Street. On the right bank of Haweswater is Naddle Forest, rising to 1427 feet, and Rosgill Moor, drained by *Swindale Beck*, falling into the *Lowther*, $1\frac{3}{4}$ mile above the infall of the Haweswater stream. Following the left bank of *Lowther* to its source past Ralfland Forest, the feeders rise on Shap Fells, at a little above the 1700-feet contour, around Wasdale Pike, 1853 feet, from which the *Leen* watershed ranges, by Low Fell, 1133 feet, and Shap Summit, at Col valley, through which the London and North-Western Railway is carried, at about 930 feet. The minor watershed, separating the waters of the *Lowther* from those of the River *Lyvenn*, runs parallel and close to the former stream, by Oddendale, 100 feet, Shap, Rosgill, Lowther Park, Newtown, Clifton, and Brougham Hall.

In 1865–6 a scheme was prepared by Messrs. G. Willoughby, Hemans, and R. Hassard, for the supply of London

from Lakes Ulleswater, Haweswater, and Thirlmere, and laid before the Royal Commission on Water Supply, who instructed Dr. W. Pole, F.R.S., to collect additional information and samples of water for analysis. The natural drainage of Thirlmere is 13 square miles of Green Slates and Porphyries; the lake was proposed to be raised 64 feet, and the drainage of several areas was to have been added to it by artificial means, viz.:—(1.) Watendlath Tarn, Blea Tarn, in Borrowdale and *Naddle Beck*, in all 5 square miles, with a very heavy rainfall and rugged surface, mostly bare of grass; (2.) North-Eastern Streams:—*Barrow Beck*, *Trout* (*Greta*) *Beck*, Mosedale Gill, and Helvellyn Gill, in all 21 square miles of drainage; (3.) Southern additions by a conduit intercepting the *Rothay* and *Easedale Beck*, and conveying the water through a tunnel under Dunmail Raise into Thirlmere, draining in all 6 square miles.

Haweswater is situated in an even still more rugged country, and in a similar geological formation; it drains 12 square miles; the lake is $2\frac{3}{4}$ miles in length and 694 feet above Ordnance Datum-line, and has an area at its present level of 400 acres. It was proposed to raise its level 42 feet by a dam at its outlet, two intercepting conduits intercepting drainage, flowing directly into the *Lowther*, viz.:—Heltondale, Gill, and *Hews Becks* to the north, and the *High Lowther* at Cooper's Green, and Swindale (with auxiliary reservoir to the south, in all 26 square miles). Mr. Bateman, F.R.S., proposed, in 1875, to raise the level of Haweswater 25 feet, and to draw from it 25 million gallons daily, in combination with 55 millions from Ulleswater for the joint supply of Liverpool and Manchester: the scheme was not accepted. Thirlmere drains into the *Greta*, which joins the *DERWENT* at the foot of Derwentwater, drains into Bassenthwaite Lake, and is separated from Ulleswater by the Helvellyn Ridge; the latter lake is divided by the *Eamont*, which also receives the *Lowther* bringing the overflow of Haweswater. It was proposed to intercept the waters of the *Lowther*, and convey them by a conduit from a point near Askham to Ulleswater, which was to be

tapped at the head by a large aqueduct, which was to be carried through or under Kirkstone Pass, by Ambleside, Kendal, East Lancashire, the Potteries, and Birmingham to London, at a cost of 12,200,000*l.*, with a daily yield of 250,000,000 gallons. Compensation reservoirs were to have been made at *St. John's Beck* below Thirlmere, and at Swindale, and the water of the *Lower Lowther*, draining several square miles of somewhat indifferent water, would also have been chiefly used for compensation purposes, which would have amounted in all to one-third of the abstracted rain. The minimum rainfall was taken at 80 inches per annum, evaporation and absorption at 16 inches, leaving 66 available, giving nearly 465,000,000 gallons daily throughout the year, one-third of which is 450,000 gallons daily for each square mile of drainage, which would have utilized floods, and doubled the volume in droughts.

The particulars of the proposed reservoirs were as follows:—

Name.	Area in square miles.	Area of reservoir in acres.	Contents in cubic feet.		Total storage.
			For supply to towns.	For compensation.	
Swindale ..	38	166	..	187,000,000	187,000,000
Haweswater ..		683	235,200,000	961,100,000	1,196,300,000
Martindale ..	95	255	336,000,000	..	336,000,000
Ulleswater ..		2300	1,742,400,000	..	1,742,400,000
Thirlmere ..	44	875	1,721,977,600	..	1,721,977,600
St. John's Beck		360	..	380,000,000	380,000,000
	177	4639	4,035,577,600	1,528,100,000	5,563,677,600

Dr. Pole estimated the water running out of Ulleswater, at Pooley Bridge (21st May, 1867), as probably 35,000,000 to 40,000,000 gallons a day, the lake being low at the time; the *Lower Lowther* he estimated at 50,000,000 gallons a day, the *Upper Kent*, 20,000,000 gallons.

Soft waters like those of Cumberland and the Welsh mountains contain a smaller proportion of gases, those waters

containing salts of lime and magnesia, and more nearly resembling distilled water.

	Distilled Waters.	Welsh Waters.			Cumberland.			Loch Katrine, Glasgow.
		Min.	Max.	Mean.	Min.	Max.	Mean.	
Nitrogen ..	1·133	1·226	1·412	1·323	1·310	1·551	1·424	1·731
Oxygen ..	·617	·566	·642	·612	·667	·749	·726	·704
Carbonic Acid	·105	·107	·335	·227	·085	·793	·281	·113
	1·855	1·899	2·389	2·162	2·062	3·093	2·431	2·548

These waters contain but little more air in solution than recently distilled water. In waters free from organic matter, the proportion of oxygen to nitrogen in the dissolved gases ought to be nearly as 1 : 2; the Bala Lake is as 1 : 2·03; Ulleswater as 1 : 2·08, the Cumberland waters are somewhat better aerated than the Welsh samples.

The complete analysis by Drs. Frankland and Odling of samples of Lake District waters collected by Dr. Pole, F.R.S.

	Thirlmere.	Upper Rothay.	Hawes-water.	Lower Lowther.	Ulleswater.
Total solid residue from 100,000 parts of water, evaporated and dried at 100° C..	2·659	3·061	3·559	9·286	3·626
Hardness in 100,000 parts before boiling..	0·7	1·3	1·3	6·7	1·9
Hardness in 100,000 parts after boiling..	0·7	1·3	1·3	6·3	1·4

With the exception of the *Lower Lowther*, which Mr. Bateman proposed to use chiefly for compensation purposes, these waters leave a smaller residue than those of Wales, and Dr. Frankland states that the storage of water appears to diminish the proportion as compared with that contained in the feeders of such lakes, which is also the case at Bala Lake, in which a residue of 2·79 parts is left, whilst that of its feeders amounts to 4·10 (average of 4 feeders).

From the infall of the River *Lowther* into the *Eamont*, to

the infall of the *Eamont* into the *EDEN*, no stream of importance falls into the Lowther. Following the left bank of the *EDEN*, by Whinfell Park, it receives the River *Leith*, at a point opposite Temple Sowerby Railway Station, the Eden Valley Railway following the left bank of the valley from Clifton Junction, this stream flows from the west, by Cliburn and Melkinthorpe, where it changes its direction, and instead of flowing directly to the *Lowther*, at Brougham Castle, flows into the *EDEN*. Rising at Hardendale, on Reagill Common on its west or left bank are Lowther and Hackthorpe; on its right bank are Little and Great Strickland, and a tributary draining Sleagill, flowing by Newby, 642 feet, and Mosland, into the River *Lyvennet*, rising at Crosby Ravensworth Fell, which passes through that village at 600 feet, descending to 450 feet at King's Meaburn, and falling into the *Leith* at about 375 feet, and into the *EDEN* at about 350 feet. On the left bank of the *EDEN* above the infall of the *Leith*, is Bolton, 420 feet, Bovley Castle and Colby, where it receives *Hoff Beck*, rising above Great Asby 600 feet above the infall, and the stream immediately below the town of Appleby, built on the left bank in a bend of the river; the 400-feet contour terminates in the stream.

The registration sub-district of Appleby, contains 60,983 acres, with a population of 5548.

From Appleby the south-east to north-west course of the river is continued to east of Little Musgrove, where the valley trends south, to the source of the *EDEN;* at the southern end of the Mallerstang trough-shaped Valley, south of Little Musgrove, on the left bank of the *EDEN*, is the infall of the *Sandal Beck*, rising at Harter Fell, and flowing past Ravenstonedale and Soulby, falling into the *EDEN* at 475 feet. Further south, on the left bank of the *EDEN*, at 550 feet above the sea, is the town of Kirkby Stephen. To the south the river basin is bordered by the hills on either side of Mallerstang Valley, rising 2323 feet to the west at Wild Boar Fell, overlooking the basin of

the *LUNE*, and to 2328 feet at High Scar on the east, overhanging the source of the *SWALE*, and forming the boundary between Westmoreland and Yorkshire; to the south the boundary leaves the watershed and follows the line of *Hell Gill Beck*, the chief source of the *EDEN;* leaving this stream, it crosses the Col valley, between the *EDEN* and the *Ure*, at 1189 feet, and ascends Swarth Fell, on the opposite side, from which it descends to the River *Rawthey*.

The registration sub-district of Kirkby Stephen contains 74,466 acres, with only 5665 inhabitants.

On the right side of Mallerstang are the remains of Pendragon and Lammerside Castles, and at the entrance to the village of Nateby, between which and Kirkby Stephen the *EDEN* is crossed by the Tebay and Darlington Railway, at about 600 feet. To the north is the village of Winton and the infall of the River *Belah*, flowing in from the east and draining Kaber and Kaber Fell, crossed by the Darlington Railway, at 900 feet. On the right bank, below Oxenthwaite, at 675 feet, it receives *Argill Beck*, traversing an outlier of the Durham coalfield, preserved by a fault; the numerous coal seams dip at a high angle in close proximity to each other on the side of the valley; they were discovered by Mr. Goodchild, of the Geological Survey. The stream rises at 1550 feet on the south side of Stainmore Common, close to the point where the railway crosses the summit-level near Barras Station. The watershed ranges across the common, parallel to the line of county boundary, but a mile to the west of it, by Iron Band, Warcop Fell, 2042 feet, Breston Fell, 2399 feet, Hilton Fell, Murton Fell, and Dufton Fells, overhanging the *TEES*, and *Lune* Dale, a tributary of that river. On the right bank of the *Belah* is the village of Brough Sowerby, 600 feet, and the river falls into the *EDEN* at 475 feet; half a mile lower down the stream is the infall of the *Augill Beck*, rising under Iron Band, and draining on its right bank Brough under Stainmore, 622 feet, and falling into the *EDEN* at Great Musgrave, below which the river is crossed by the Eden Valley Rail-

way, which follows the right side of the valley, by Warcop, Sandford, Coupeland, Crackenthorpe, and Brampton, between which and Kirkby Thorpe is *Trout Beck*, draining Dufton and Long Marton; at Skygarth, south of Temple Sowerby, the railway again crosses the river, running to Clifton Junction, in a tributary basin.

The north-east trend of the valley of the *EDEN* is continued by Culgaith, Long Wathby, and Little Salkeld, near which two streams, draining the Cross Fell range, find their outfall at the same point; the southern is *Briggle Beck*, composed of two feeders, one draining Kirkland and Skirwith, and *Blencairn Beck*, on which are the HANGING WALLS OF MARK ANTHONY. Above the streams Cross Fell rises to 2892 feet, and Ousby Fell, 2429 feet; northward the watershed ranges by Melmerby Fell, 2331 feet, and Fiends' Fell, 2082 feet, between which and Hartside Heights, 2046 feet, there is a slight depression, through which is carried the road from Penrith to Alston.

From the foot of the steep escarpment, at about 600 feet, a long slope commences, trending to the river, which is intersected by numerous streams, whose valleys are cut through the Glacial Drift, and occasionally into the underlying Penrith Sandstone, draining Melmerby, Gamblesby, and Glassonby.

Kirkoswald is at the outfall of *Raven Beck*, draining the valley above Renwick. A mile and a half lower down the valley is the infall of *Croglin Water*, rising on Black Fell, 2179 feet, overlooking Gilderdale Forest.

The registration sub-district of Kirkoswald contains 65,578 acres, with 5764 inhabitants.

In the Cross Fell range the watershed does not define the county boundary, which, however, after traversing Gilderdale Forest up Gilderdale Burn, ascends the Fell west of Middle Carrick, and runs north-north-west along the crests of Farlam Carrick, Great Blacklaw Hill, 1952 feet, Cold Fell, 2059 feet; here the county boundary again leaves the watershed, and follows streams flowing east into the River *TYNE*.

The watershed trends north-west from Cold Fell, and

descends to 1241 feet at Kelky Fell, from which it trends north-east, by Denton Fell, 838 feet, descending to about 575 feet, between Gilsland and Thirlwall Castle, at which point it is crossed by the Carlisle and Newcastle Railway, in a cutting, between Upper Denton and Greenhead; still continuing a north-east direction, it traverses Thirwall Common, rising 855 feet at Burn Divot, and 1065 feet at Round Top, forming the eastern limit of the valley of the Irthing; at Round Top the watershed turns abruptly to the north-west, as does the river, which runs parallel to it, and ascends to 1613 feet at Humble Hill; westward, the watershed runs on and becomes the county boundary between Northumberland and Cumberland, but it separates the *TYNE* from the waters of the *LINE*. The Eden Watershed, leaving it at Sighty Crag, 1702 feet, running south to Greyfell Common, and High Grains Waste, 1211 feet, thence trending south-west.

River Irthing.

Following the right bank of the *EDEN* from the infall of the *Croglin*, it is intersected by the 200-feet contour; passing Great and Little Corby, it receives the River *Irthing*, after which it changes its direction and flows west; following the left bank of the *Irthing*, it receives small streams from Hayton Hill; at 95 feet it receives the River *Gelt*, rising in the wild valley of Geltsdale, and draining Castle Carrock on the left bank and Talkin Tarn on the right.

On the left bank of the *Irthing* is Brampton and Naworth Park. Eastward the railway runs parallel to the valley as far as Gilsland, when it turns to the north-north-east, and the stream drains a wild moorland country varying from 600 to 1700 feet.

Following its right bank, by Bank, past Gilsland Spa, is the infall of *Cam Beck;* on the left of the latter is Walton, and Newtown, below which, on the right bank of the *River Irthing*, is Irthington and Newby, below which it falls into the *EDEN* at 50 feet above the sea; the top of the valley

on the right bank by High Crosby and Tarraby only averages 100 feet. At Cargo, Rockcliff, and Wetheral it only rises to 50 feet. The watershed at Blackford is only 58 feet, and ranges through the mosses south of Tod Hills.

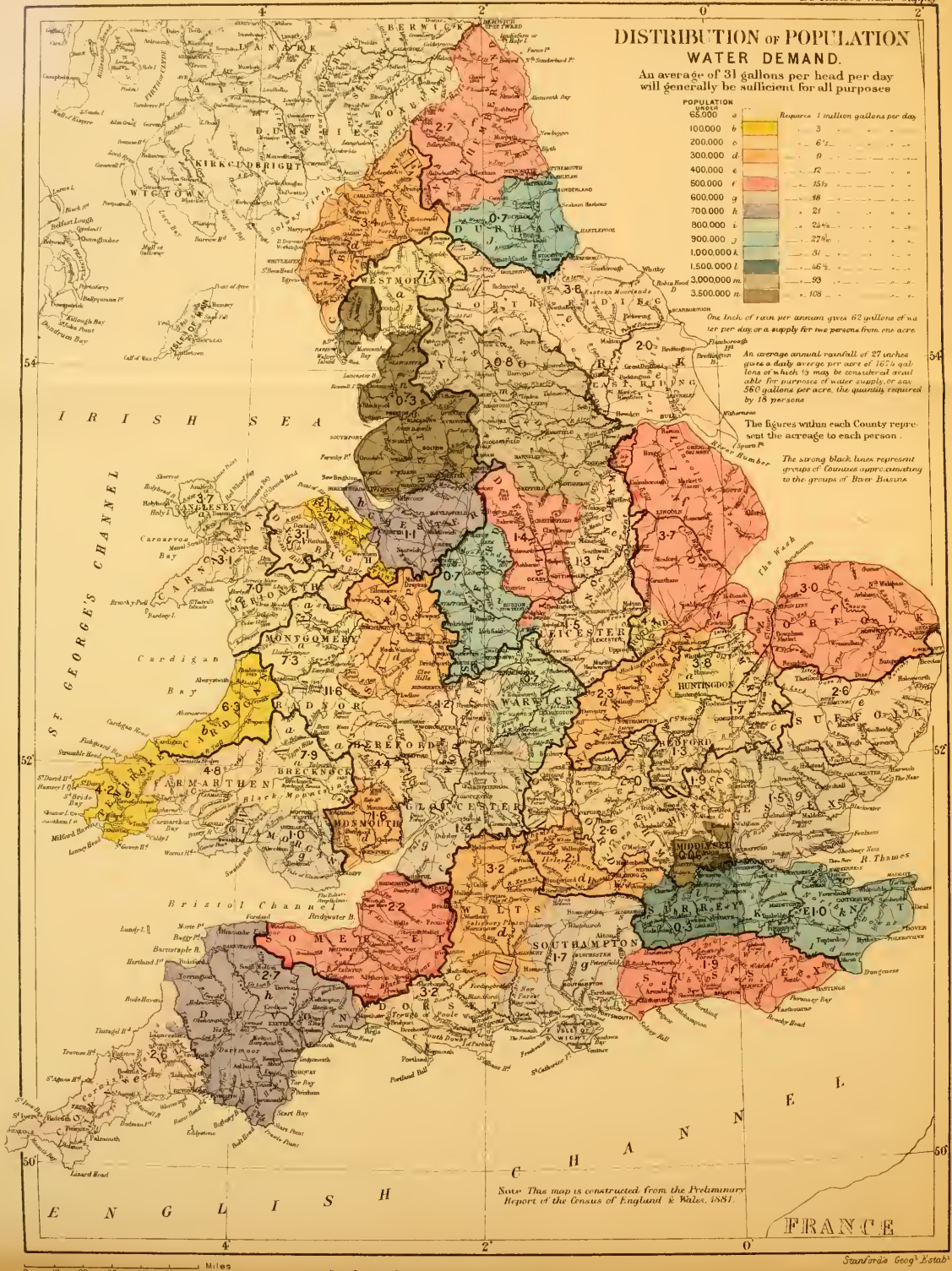
RIVERS LINE (VII.) AND ESK (VI.).

Length of the *LINE*, 20 miles; area, 104. In considering the geological formations existing in this basin, it will be convenient to consider it with that portion of the basin of the Scotch River *ESK*, that drains a distance of 21 square miles within the English border. The *LINE*, and the English portion of the *ESK*, drain 7 square miles of Silurian, 89 of Carboniferous Limestone, which is largely made up of Sandstone and Slates, 13 square miles of Permians, and 21 of Trias, of which 7, lying south of the *LINE*, are Stanwix Marls, and the remainder Kirklinton Sandstones.

The *ESK*, between Todhill and Gretna Junction, is crossed by the Caledonian Railway and the great Scotch road; immediately above the bridge of the latter it receives the River *LINE;* on the left bank of the latter is Westlinton and Kirklinton at 50 feet; at 275 feet it receives the *White Line*, flowing past Lime Holme Ford at 375 feet; at 400 the latter receives *Kirk Beck*, draining St. Cuthbert's, Shepford. The main stream, above the infall of the *White Line*, is called the *Black Line*, rising in Bewcastle Fells, on Glen Dhu, 1500 feet above the sea. On the right bank there are no tributaries or villages of importance.

Following the left bank of the *ESK*, and ascending the valley, is Longtown and Kirkandrews-upon-Esk; the North British Railway is carried along the left bank of the stream, entering Scotland at the infall of *Kers Hope Burn* at 300 feet above the sea. After receiving on its left bank the *Liddel Water*, the *ESK* passes into Scotland; for a considerable distance the River *Liddel* forms the boundary between Scotland and England.

The registration sub-district of High Longtown contains



London; Edward Stanford, 55, Charing Cross, S.W.
Stanford's Geogl Estabt

48,824 acres, with 2358 inhabitants; of Low Longtown contains 39421 acres, with a population of 5352.

On the north bank of the estuary of the River *ESK* is the infall of the River *Sark*, near Gretna Green, which for a few miles forms a boundary between England and Scotland. The Scotch coast, from the north of the *SARK* to *ANNAN*, consists of St. Bees Sandstone; while still further west, from Caerlaverock Castle to Dumfries, the Penrith Sandstones, absent in the Carlisle area, reappear:—

Population of Solway Firth Streams in 1871.

County.	Population.	Density. Acres per Individual.	Probable proportion living in this Group.	Probable Population.
Cumberland	220,245	4·5	$\frac{17}{22}$	170,157
Westmoreland	65,000	7·4	$\frac{1}{2}$	32,502
In 1881.				
Cumberland	250,630	3·4	$\frac{17}{22}$	193,664
Westmoreland	64,184	7·7	$\frac{1}{2}$	32,092

CHAPTER XXXV.

ON THE PROPAGATION OF EPIDEMICS BY POTABLE WATER.

The researches of M. Chaveau,* confirmed by Dr. J. S. Burdon Sanderson, F.R.S.,† prove incontestably that the virus of small-pox, sheep-pox, and glanders resides in the finer suspended matter, *granulations élémentaires*, and not in the serous fluid of suspension; when these organic granules were removed, the fluid, though containing soluble, unorganized materials, was perfectly incapable of communicating the disease to the animal inoculated. The minute organized granules are the poisonous agents, that after finding a suitable *nidus* in the bodies of animals, then multiply spores, and produce the specific disturbance of the normal vital functions characterizing diseases of the zymotic class. The germs have as yet not been isolated or individually recognized, but no doubt remains that the greatest dilution of a virus, such as vaccine matter, has no effect on the virulence of the disease or result produced, though the inoculation becomes uncertain, as the operator may fail to convey to the wound a single germ. Similar experiments upon the virus of small-pox, of sheep-pox, and of glanders led to similar results.

It is a fact that zymotic germs containing the poison of cholera and typhoid or enteric fever are communicated occasionally from individual to individual, through the air, but the larger majority of cases are due to the use of drinking water containing, disgusting as it may appear, the dis-

* 'Comptes Rendus de l'Académie des Sciences,' tome lxvi., 1868, pp. 289, 317, and 359.

† 'Twelfth Report of the Medical Officer of the Privy Council,' 1869.

charges of patients suffering from these diseases. The history of the *cholera* visitation in London throws much light on the facility with which a disease may be propagated by water.

The respective condition of water supply and cholera mortality were as follows:—

		Character of water supply.	Total mortality from cholera.	Mortality from cholera per 10,000.
Epidemic of	1832	Polluted	5,275	31·4
	1849	Very much polluted	14,137	61·8
	1854	Less polluted	10,738	42·9
	1866	Much less polluted	5,596	18·4

In 1832, London was chiefly supplied with water from the *THAMES* and *Lea*, and shallow wells, populations were smaller on the banks of the rivers, and no efficient system of sewerage existed; this, in 1849, had been carried out, and the *THAMES*, *Lea*, and *Ravensbourne* were converted into a perfect organization for the diffusion of sewage into the drinking water for daily consumption by the inhabitants of London, the mortality varied directly with the amount of pollution. Dr. W. Farr, F.R.S., pointed out to the then Registrar-General, that of the metropolitan population supplied by water taken from the *THAMES* at Kew only 8 died in 10,000, while of those supplied from the *THAMES* at Hammersmith 17 died; of those in Belgravia, Chelsea, and Westminster using water taken below Chelsea Hospital 47 died; and in districts drawing their supplies between Hungerford and Waterloo Bridges, where the river was in an exceedingly bad condition, the deaths were 163 to 10,000 inhabitants. In 1854 the *Southwark Company*, supplying Bermondsey, still drew its supplies from Battersea, close to one of the sewers, and the death-rate was greater than before. In Lambeth the rate fell from 1618 to 904, through being partly supplied with water by the *Lambeth Company*, who had moved in the interim their intake to Teddington, beyond the range of

the London sewage; the difference of the rate in the same district being 40 per 10,000 supplied by the *Lambeth*, and 130 per 10,000 supplied by the *Southwark and Vauxhall Company*. This gigantic crucial experiment, performed on half a million of people, conclusively proved, as pointed out by Mr. John Simon, F.R.S., the cause of the great mortality. In the next epidemic period, 1866, both companies supplying the south of London had moved their intake to a purer part of the *THAMES*, and the cholera mortality here was comparatively insignificant. The disease in high development was confined to certain parts of the east of London, within the area of the *East London Waterworks Company*, and further restricted to that portion of their district which they supplied with water they obtained from a polluted portion of the *Lea*, stored unfiltered in uncovered reservoirs at Old Ford, supplied when the filtered water ran short early in July. July 10th, there were no deaths, on July the 31st there were 171 deaths, on August 1st, 170, on which day the Company was warned by the Registrar-General, and the deaths diminished on August 2nd to 155, and declined daily to 8 on September 1st.

The parish of ST. JAMES, WESTMINSTER, occupies 164 statute acres, with a population of rather less than 40,000, which has not varied much between the census of 1831 and 1851. In the cholera visitation of 1832 there were only about 45 deaths; the sanitary condition was improved, and in the epidemics of 1848–9 there were only 3 deaths. In 1850 there were 4 fatal cases, in 1851 and 1852, 1 case in each year. In the last four months of 1853 cholera became again epidemic in London, and 7 deaths in the Great Marlborough Street and Poland Street district. In the following year cholera was present in the spring, but no deaths took place in St. James's until the week ending the 5th of August; in the following week there were 5 deaths, then 12, then 6, then 78, and in the week ending September 9th, no less than 287, after which it declined, the last death being in the week ending October 7th, showing its gradual approach, a lull in its operation, and

then the sudden terrible outburst, outstripping the most energetic efforts to mitigate its effects. The investigations of Dr. Snow show the outbreak was principally confined to the area about the Broad Street pump. That 61 out of 73 persons who first died used the pump water. That the water was used for various purposes. That in the workhouse in the centre of the affected area, where the water was not used, only 5 deaths occurred, while 50 would have been the proportionate death rate. That in a factory using the water, 18 died out of 200 persons employed. That in the Brewery, with 70 men employed, who did not drink the water, none died. That sporadic cases occurred through people sending for the water from a distance. That the mortality diminished in the neighbourhood of other pumps. That out of 14 houses in a street, the 4 that escaped without a death did not use the Broad Street pump; and from these facts Dr. Snow deduced the result, that the outbreak was caused by the dissemination of cholera poison by the contamination of the Broad Street well, by the evacuations of a cholera patient from a neighbouring cesspool.

The district consists of 20 to 30 feet of sand and gravel, of an exceedingly porous nature, and is overlaid by 8 to 12 feet of made ground; pump wells are numerous, sunk down to the London Clay, which supports the water. The sides are built of bricks laid dry, through which the water enters. The arches are turned over with brick, laid in mortar or cement, and covered in with a keystone. Many of these wells, including the Broad Street, can soon be pumped dry. Analysis of the water at the latter well shows so large a quantity of common salt (chlorine, 11·240; soda, 16 861), that it must be derived from the *débris* and refuse accumulated in a densely populated district, and not from the waste water of the neighbourhood, which is supplied by the *Grand Junction Water Company*, who pump the *THAMES* at Kew, which there contains of chlorine, 0·84, and of soda, 0·84. A considerable quantity of nitric acid also occurs, which is believed to be derived from decayed animal matter, an

possibly from pest-field soil. This field corresponded to the present Craven Estate, which was given in 1687 by William, the renowned Earl of Craven, to the poor, to be used as a field, on which to erect pest-houses, in case of the reappearance of the plague. The Earl, who fought under Gustavus Adolphus, and married Elizabeth, daughter of James I. and Queen of Bohemia, lived at Craven House, Drury Lane, throughout the whole of the time of the plague, 1665–6, and died in 1697. The field, which was first hired and afterwards bought by the Earl, became the cemetery for the thousands who died in the 36 pest-houses on it.

In 1734 the ground had become built over, and the charitable trusts were transferred to other lands near Byard's watering place, now Bayswater. The width of the pest-field from Marlborough Row to Dufour Place is 4 chains, its length 8 chains, extending between Craven Chapel and Broad Street. That the public water supply did not conduce to the spread of the disease is proved by part of the district, simultaneously affected, being supplied by the *New River* and *Grand Junction Companies*, and it is exceedingly unlikely both companies should have their supplies polluted, though indirectly the mode of supply conduced towards the outbreak, the water being stored in unwholesome and contaminated cisterns and water-butts, causing the people to have recourse to the pump, which yielded sparkling and apparently pure water.

Windmill Square, Shoreditch.—In 1848–9 this intense outburst was fortunately limited to 5 houses, inhabited by 22 persons, half of whom died in a few days, the details of which are recorded by the late Dr. Gavin.* The water supply was from a well 18 feet deep, which, losing its water through the formation of a sewer, was deepened another 6 feet, and an unfailing supply obtained. The overflow of the cesspools was carried to a pit dug in the centre of the small square,

* Appendix B, 'Report to General Board of Health on Epidemic Cholera,' 1848–9.

and percolation from this made its way into the well, with the fatal results recorded.

The direct relation of cholera to drinking water is remarkably shown in a case given by Snellen at Utrecht, and a case given by Dr. Ballot, of Rotterdam; those who drank the waters of the "Polders" (reclaimed lands) died at the rate 17·7 per 1000; those who drank the well waters 16·8 per 1000; those who drank river water 11·9 per 1000; those who drank rain-water filtered 5·3 per 1000. The City of Amsterdam, supplied by an aqueduct from rain falling on downs near Haarlem, only lost 4 per 1000. In Rotterdam the mortality fell one-half on pure water being supplied.

The cholera outbreak at Merthyr Tydvil in 1849 was due to atmospheric infection; the town was expanding, and undrained and unpaved, and ashes and refuse were thrown in front of the houses, and then blown in all directions. To dry ash-pits at Liverpool, often placed in the houses, was due the cholera outbreak of 1866, and to a similar origin was the cholera outburst in 1867 at Zurich, which was traced by Dr. A. Fick, then Professor of Physiology in Zurich, to a child brought from Rome, where cholera was epidemic. These facts show the necessity of preventing the distribution of dry sewage matters in the atmosphere.

The remarkable immunity from cholera, in affected districts, has been shown by the late Sir William Lawrence, F.R.S., Her Majesty's Sergeant-surgeon, who stated that prior to the year 1825, "Bethlem Hospital" and the "House of Occupation," in St. George's Parish, Southwark, were supplied by the *Lambeth Waterworks Company*, but the water leaving a muddy sediment, an artesian boring for water was made 220 feet deep. Not a single case of cholera occurred in 1832, 1849, or 1854, though the neighbourhood suffered severely.

The inhabitants of Manchester and Salford were supplied with polluted water from the *Irwell* and from shallow wells previous to 1851. In the outbreak of cholera in 1832 there were 890 deaths, in that of 1849, 1115 deaths, while

in 1854, with an improved water supply, notwithstanding the increased population, 50, and in 1866, 88 deaths, or $\frac{1}{10}$th of the previous amount.

In WIGAN, prior to 1866, the only water supply was derived from polluted shallow wells, and in 1849 cholera killed 348 persons. In the 1866 epidemic only 58 died, though the drainage was very imperfect.

SOUTHAMPTON.—The outbreak of cholera in June 1866 is ascribed by Dr. E. A. Parkes, F.R.S., Professor of Hygiene to the Military Hospital at Netley, to choleraic patients arriving in the Peninsula and Oriental steamship "Poonah" from Alexandria, caused by cholera-poisoned water in a tank opened on the voyage, the source of which is unknown. The sick men were brought on shore at a time when the water supply was deficient, and the drainage of the western part of the town, usually raised by pumping into the eastern portion, and carried to the outfall, was stagnant, to allow the cleansing of the sewers. In the beginning of July the steam pump, working night and day, recommenced work, and the air became charged not only with overpowering effluvium, but with minute particles of sewage. These invisible globules were carried to the clean, airy houses in the neighbourhood of the pumping station, and an outbreak commenced that carried off 107 persons. On the 18th of July an iron culvert was substituted for the open channel, and the outbreak at once declined.

Diarrhœa.—Dr. Farr states that this is a common name for a symptom—loss of serous fluids to the blood—produced by various causes, and probably covers diseases as distinct as those confounded under the name of "fever" until separated by the sagacity of Dr. Jenner. The severe diarrhœa, which has been very fatal to children since 1846, Dr. Farr regards as a form of cholera. At Croydon, in 1854, Dr. Carpenter showed the presence of suspended sewage in the drinking water produces choleraic symptoms. Suspended vegetable matter in water will produce diarrhœa. This was

especially found to be the case in the late American Civil War, after drinking surface and ditch water.

Sulphate of lime and magnesium also produce the same effect, especially upon strangers. This has been found in the selenitic water of Paris, and was especially investigated by Parent-Duchâtelet at the Prison of St. Lazare. Similar effects are produced by the presence of nitrate of lime and by brackish waters, whether from salts in the ground or from the infiltration of air water, and by the absorption of sulphuretted hydrogen and other sewer gases by the water in tanks and cisterns.

Dysentery.—Dr. Parkes believes the causes that lead to this disease are suspended animal organic matter, earthy matters, calcium, and magnesium, sulphates and chlorides, calcium and ammonium, nitrates, large quantities of sodium and magnesium, and chloride in solution. Several of the old army surgeons knew of this cause. Champouillon records a cure where two regiments used the impure water from the Canal de l'Ourcq, near Paris; one regiment mixed the water with red wine, the other with brandy. The regiment that mixed the water with red wine or coffee, the tannin of which united with the organic matter, had no dysentery; the regiment using brandy, which precipitated the organic matter against the sides of the vessel, where it putrefied, suffered from dysentery, which was at once stopped by the substitution of red wine for brandy.

The Rivers Pollution Commission gives a table of the mortality from cholera in the four visitations, and the average mortality from diarrhœa (see p. 584).

Typhoid fever.—Is endemic in this country, and annually carries off 15,000 persons in England and Wales alone, due in the larger number of instances to the consumption of water polluted by sewage, if not by typhoid sewage, by the individual attacked, its conveyance from infected to healthy

	Nature of water supply.	Organic element in 100,000 parts.	Total hardness in 100,000 parts.	Population in 1871.	Cholera per 10,000.				Diarrhœa per 10,000.	All causes per 1000.
					1832.	1848–9.	1853–4.	1865–6.		
Bath	Polluted springs	·161 to ·350	16·3 to 31·3	52,557	..	12·89	..	0·15	8·22	22·2
Birkenhead	Deep wells ..	·062 – ·079	5·7 – 9·9	65,971	..	24·32	7·52	12·70	12·42	24·0
Birmingham	Shallow and deep wells ..	·124 – ·667	12·6 –127·1	343,787	..	1·67	·98	·47	20·03	24·3
Bradford ..	Shallow wells..	·204 – ·661	6·4 – 7·1	145,831	..	23·41	1·86	1·73	13·24	26·0
Brighton ..	Deep wells ..	·057 – ·066	21·2 – 21·5	90,011	..	29·59	5·80	1·80	12·26	22·6
Bristol.. ..	Surface wells ..	·177	24·5	182,552	52·44	80·32	11·69	1·68	9·96	23·9
Cardiff.. ..	Upland waters	·243	20·0	39,536	..	85·18	48·40	13·04	7·63	21·3
Carlisle ..	Deep wells ..	·204	29·3	13,765	132·46	12·27	5.05	·45	9·91	24·1
Croydon ..	Deep wells ..	·047	22·0	71,319	..	29·48	28·22	3·23	9·45	19·9
Exeter.. ..	Surface wells ..	·243	7·7	34,652	123·05	13·40	3·05	33·49	10·12	25·5
Hull	Deep wells ..	·061	25·4	121,892	104·93	..	..	..	..	25·2
Leeds	Upland waters	·283	8·3	259,212	56·89	122·25	4·26	1·32	19·78	28·5
Liverpool ..	Upland and deep wells ..	·004 to ·109	6·2 to 14·9	493,405	92·20	128·77	31·35	40·13	19·16	34·0
London ..	Surface wells ..	·021 – ·765	15·5 – 32·1	3,254,200	87·09	59·84	45·46	19·96	10·49	20·6
Lynn	Surface wells ..	·218	16·9	16,562	36·65	·98	4·38	.60	6·21	22·8
Maryport ..	Upland waters	·251	3·4	15,719	..	..	..	..	..	..

persons being similar to the conditions under which Asiatic cholera is propagated.

Riecke* gives a *résumé* of the progress of knowledge on this subject. In 1760 the use of impure water was in part attributed as the cause of the "schlien-fieber," at Göttingen, in 1822; a similar cause was assigned by Walz to the outbreak of "typhus" (typhoid) at Saarlouis, in Rhenish Prussia; in 1843 Müller discovered that 129 cases of "typhus abdominalis" (typhoid), and 21 deaths occurring in the garrison at Mayence, were due to polluted water supply. In 1848 Dr. E. A. W. Richter proved a similar cause for an outburst at a school in Vienna.

Dr. Parkes† continues this list: in 1852 Dr. Austin Flint published the particulars of a similar outbreak in North Boston (Erie, U.S.) in 1843. In 1852–3 a severe outbreak of typhoid at Croydon was shown to be due in great part to pollution of drinking water from cesspools. In 1856 Dr. Routh published a similar case at Hastings, and, in 1857, Dr. Budd two other well-attested cases. In 1860 an outbreak due to this cause occurred at the Convent of Sisters of Charity, Munich; out of 120 persons 31 were attacked, and 24 died. The fever disappeared with change of water supply.

London.—Surgeon Major A. C. C. Renzy gives an instructive account of the extinction of typhoid fever in the Millbank Prison by the disuse of *THAMES* water, in the 'Lancet' of Jan. 8th, 1872. The prison was opened in 1816, and had a bad reputation for unhealthiness; the cholera epidemics of 1833, 1847, and 1853–5 were very fatal, and phthisis and typhoid were ever present up to August, 1854. On the 10th of that month the water supply was changed from the *THAMES*, as it flows past the institution, purified by filtration, to the artesian well in Trafalgar Square. Six days after, cholera, which was the epidemic in the prison, ceased, and the typhoid death-rate, from 1845 to 1854, of 5·7 per

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* 'Der Kriegs und Friedens-Typhus.' Nordhausen, 1850.

† 'Hygiene,' p. 45, 5th ed.

thousand was reduced to three deaths from typhoid between 1855 and 1872, all of which were contracted before the patients were imprisoned. Practically typhoid disappeared with the disuse of *THAMES* water, all other sanitary conditions remaining the same.

Terling, Essex.—In the autumn of 1867, out of 900 inhabitants, 300 were attacked with typhoid fever, and 41 died. The village is built on the sloping banks of the *Ter*, an affluent of the River *BLACKWATER*. Dr. Thorne Thorne, of the Local Government Department, reports that the subsoil is clay overlaid by sand and gravel; previous to the epidemic was a drought, followed by a heavy rainfall and rise of water in the wells, which washed out a mass of polluted matter, which had accumulated in the loose and porous soil. Two wells, that were not so circumstanced as to be affected by those conditions, supplied two groups of cottages that were not affected by the epidemic fever.

Chichester in 1865 was severely visited by typhoid and low fever, and was inspected by Dr. Edward C. Seaton, of the Medical Department of the Privy Council. It is built on 20 feet of gravel, resting on impermeable clay. The gravel receives the drainage in shallow holes, or cesspools, and the water supply is taken from deeper holes, or wells in the same material; in some cases where fevers had occurred these were only within 3 feet of each other. The greatest contamination took place during droughts and after heavy floods, washing sewage into the wells.

Salisbury.—From 1844–52 the annual mortality from typhoid was 7·50 per 1000 inhabitants, supplied with water from shallow wells, with water standing 2 to 3 feet from the surface, close to cesspits, often overflowing. In 1853 public waterworks and drainage works were commenced, and were completed in 1856; the water was obtained from a well 68 feet deep in the chalk, connected with a tunnel 70 feet long, yielding 46 gallons per head per day; these works reduced the death-rate from typhoid to 1·75 per 1000 for the eight years, 1857–64.

Congleton.—Sporadic cases of typhoid fever occurred in the village prior to 1866, when a violent outbreak took place, investigated by Dr. Buchanan, who states that out of 1150 inhabitants, 150 were attacked and 14 fatally, of which outburst a badly-polluted shallow well was the focus, 15 feet in depth, and containing, according to Dr. Miller's analysis, 15,145 parts per 10,000 of private sewage contamination.

Page Green, Tottenham.—In 1864 and 1865 a severe outbreak of typhoid fever affected 100 persons, and was investigated by Dr. Seaton, of the Medical Department of the Privy Council, who found it to be due to the use of surface-water from shallow wells, and in preference to the hard water supplied by the Local Board.

Guildford.—In September 1867 sporadic typhoid fever became epidemic, 150 cases occurring in a fortnight; of the 1675 houses then in Guildford, only 928 were supplied from the public waterworks, fed by two wells in the chalk, 20 feet deep, situated at the lowest part of the town; an old well from which the water is raised by water power, and a new well, from which water was distributed to the higher parts of the town by pumping engine power. Of the remaining 747 houses the supply is obtained from private wells, or from the River *Wey*. Ten days before the outbreak 330 houses had exceptionally received their water from a service reservoir, which had been filled from the new well sunk in the lowest part of the town, close to several sewers, the brickwork of which was defective, and allowed percolation into the well.

The water-line in the chalk under the town is stated by Dr. Buchanan to be very constant; in the higher part it is considerably below the surface, and cesspools sunk into it are dry and inoffensive; but the lower part of the town is water-logged, and powerful springs flow into the river. The polluted well has since been abandoned, and another sunk on an island in the *Wey*, out of reach of leakage.

Southampton.—Dr. E. A. Parkes, F.R.S., Professor of Military Hygiene in the Army Medical School at Netley,

traces the origin of an outbreak of typhoid fever to the impregnation of drinking water with contamination of sewage, probably of typhoid sewage.

Clifton, Bristol.—In the autumn of 1847 an outbreak of typhoid fever occurred, which was the subject of the most careful investigation by Dr. William Budd, F.R.S., of Bristol, whose painstaking and persevering research has in a great degree contributed to establish accurate knowlege of the propagation of typhoid fever through the agency of air and water. The outbreak took place in a crescent, called Richmond Terrace, of 34 houses, of which 13 were affected, drawing their water supply from a pump tainted with sewage. The inhabitants of the houses not so supplied were not affected.

Cowbridge, S. Wales.—A violent outbreak of typhoid fever occurred here, affecting a large number; 140 persons attended two public balls, held in the chief inn, in November 1853, and of them 8 died; this was found by Dr. Budd to be due to sewage poison in the well from which the drinking water was taken, which had received typhoid poison from a typhoid patient who was staying in the house immediately before the ball. The sanitary defect was soon after discovered and remedied.

Winterton, Lincolnshire.—This market town is well situated on a gentle slope, draining north into the *HUMBER*, and is built on porous oolitic limestone, and enjoys an excellent system of drainage, but has had a prevalence of typhoid fever for some years; in 1867 Dr. Thorne Thorne inspected the place for the Local Government Board, and found all the houses affected drew their water supply from polluted wells.

Wicken Bonant, Essex.—An outbreak of typhoid commenced here on July 25, 1869, which attacked during the autumn 45 persons, and carried off four. The causes were carefully investigated by Dr. Buchanan, for the Medical Department of the Privy Council, aided by Mr. W. H. Penning, of the Geological Survey. The village numbers 40

houses, with 206 inhabitants. It is situated in a valley cut through the Boulder Clay, and scooped out of the gravel beneath, in the channel of a brook running through the village from west to east, the rain-water resting directly on the Chalk. The Gravel is 20 feet thick, and has an irregular base of plastic impervious Clay, which prevents the downward percolation of the drainage received by the Gravels, which flowing through them to the lower part of the valley, is there partly intercepted by the parish well, 250 yards from the point where sewage is discharged. In May, water was flowing in the brook, and there had been heavy rain; in June the whole of the underground water was falling; in July the brook was dry, and water absorbed by the gravel passed directly to the well, 35 yards distant, receiving unchanged specific typhoid poison, which affected no less than 46 per cent. of all the persons that used this well for their water supply.

The Royal Commissioners, commenting on these examples, said, that the existence of specific poisons producing cholera and typoid fever cannot be denied, disseminated in such fine particles as to be able to pass through ordinary sand and domestic filters, and to be carried by the air, in the form of dust, or in the spray of liquids. They further consider that, when the poison is concentrated, the disease appears suddenly, the period of incubation being short, and the number of individuals attacked large, while, with a very attenuated poison, only those who are very susceptible will be infected, and that even concentrated poison may fail to affect persons with extraordinary powers of resistance; such as that conferred, in typhoid fever, by a previous attack of the disease. Boiling the infected water for half an hour is a probable means of destroying its power of communicating these diseases.

The following conclusions are drawn from these statistics. That the extinction of typhoid and other similar diseases is within the range of practicability; that the extinction of one class of zymotic disease is not necessarily followed by

another; that since some of the ablest physicians in London failed for many years to detect the true cause of the unhealthiness of Millbank Prison, and assigned causes for it which later experience has found to be unconnected with it, the probability is that a similar error is frequently made elsewhere, and that the prevalence of some zymotic diseases is ascribed to locality, malaria, heat, cold, visitations of temperature, moral depression, and other intangible influences, which would be entirely removed by the general disuse of impure water.

Caterham and Redhill.—An outbreak of typhoid fever occurred simultaneously at these two towns, followed in a few days by cases at Earlswood, Bletchingley, and Nutfield, in all reaching 196 cases in a fortnight, at villages 3 to 10 miles apart. The infected district is supplied by the *Caterham Waterworks Company*, drained from wells in the chalk 500 feet deep, sunk at the southern extremity of the high-lying ground which bounds the Caterham Valley to the west. In the latter part of 1878 and the beginning of 1879, an adit-level, 6 feet by 4 feet, was driven 90 feet from the old well, at a depth of 455 feet from the surface, to connect a new borehole, by the Diamond Boring Company. Dr. Thorne Thorne, who investigated the cause for the Local Government Board, finding that none of the 1400 houses not using the Company's water in the infected district were affected, examined the Waterworks, traced the initiation of the epidemic to the pollution of the water in the adit by a man employed there from the 5th of January, who was actually suffering from enteric fever, and who was obliged to leave work on the 20th of January from the severity of the attack, and on the 2nd of February the epidemic broke out, causing 21 deaths.

The Rivers Pollution Commissioners tabulate the results given in the 9th Report of the Medical Officer of the Privy Council, 1866, p. 35, showing the improvements of public health which result from proper works of drainage and water supply.

Twenty-four towns are enumerated, varying in 1861 in population from 160,714 at Bristol, to 3840 at Ashby; the improvement works were carried out between 1843 and 1857. The improvements reduced the death-rate per 10,000 by 70 at Merthyr, by 116 at Cardiff, by 102 at Newport, by 47 at Croydon, and 61 at Macclesfield; by 41 at Brynmawr, giving for the 6 towns (25 per cent. of the towns improved) an average reduction of death-rate of 73 per 10,000, or 7 per 1000. Examining the statistics to see where the gain takes place, it is noticeable that all these 6 towns had a typhoid fever death-rate of over 14 per 10,000, reaching 23·5 at Brynmawr, which was reduced to 5·5 (Croydon), and a maximum of $10\frac{1}{4}$ at Brynmawr. In the other 18 towns there is only one instance of a higher fever death-rate, viz., $12\frac{3}{4}$ at Chelmsford, which town stands in the unenviable position of having a higher death-rate after the works than before. Diarrhœa was reduced by the works from $17\frac{1}{4}$ per 10,000 at Cardiff, to $4\frac{1}{2}$ and 50 per cent. in four of the other six towns. Cholera shows most markedly the good results effected. At Merthyr, in the epidemic 1848–9, the death-rate was 267 per 10,000, 84 in 1854, and only 20 in 1866; at Brynmawr, 100 in 1848–9, and none in the next two visitations.

Goitre is defined by Dr. Aitken * as "a specific affection of the thyroid gland induced by the persistent use of water which has percolated through magnesian limestone rocks, or strata, and containing the soluble salts of lime in solution." He refers to the counties of Yorkshire, Derbyshire, and Nottingham, in all of which there are Magnesian Limestone of Permian age, but he also adds Hampshire and Sussex; in the case of these counties it is not so evident from whence the source of the magnesia is derived.

In England, Professor Lebour † states, it is absent on the alluvial deposits, Glacial Drift bed, and the Tertiaries of the

* 'Science and Practice of Medicine,' p. 658, vol. ii. 6th edition, 1872.

† 'On the Geological Distribution of Endemic Goitre in England,' by Professor G. H. Lebour. Privately printed, 1881.

London and Hampshire basins. Endemic cases occur on the Chalk-with-flints, at Newhaven, in Surrey, Hampshire, and Dorsetshire, and around Beaconsfield, Bucks, but it disappears when the sufferer removes to the latter town itself, which is on the Tertiary. It is present on the Upper Greensand and Gault of Sussex and Kent, and on the Lower Greensand, of Ampthill, Bedfordshire. It occurs sparingly on the Weald Clay, and Hastings Sand at Speldhurst, and the neighbourhood of Tunbridge Wells. It is unknown on the Oolites, except at Helmsley. It is very rare on the Lias, but is present at South Petherton.

In Cheshire, goitre, contracted in the Carboniferous Limestone country, is cured by removal to the New Red Sandstone, according to Dr. Moffat, of Hawarden. But goitre is endemic on the New Red of Wombourne, near Wolverhampton, and Crediton in Devonshire. Professor Lebour points out that it is the Carboniferous Limestone, and not the Magnesian districts, that are the hotbed of goitre, especially at Stoney Middleton and Hawes.

In France,* the distribution of goitre can be traced through the examination made by a medical council, of the men coming up for military service. This evidence was carefully weighed in 1848, by a Commission appointed by the Sardinian Government, and more recently by Dr. de St. Lager, of Lyons, who published, in 1867, a mass of information on the subject, from which it appears that goitre, though frequent on limestone, is not confined to it; that altitude, marshes, and deep valleys have no special influence on it.

In France, the distribution of endemic goitre coincides with the occurrence of metalliferous deposits, especially of iron-pyrites.

Calculous disease, in relation to water supply, has been carefully studied by Dr. Thursfield,† especially in regard to

* 'Etudes sur les Causes du Crétinisme et du Goître Endémique.' 8vo. Paris, 1867.

† 'Report on the Borough of Shrewsbury,' 1877.

the records of Salop Infirmary, where, from 1747 to 1877, out of 118 cases occurring to natives of the town, no less than 81 occurred prior to 1820. About this time the use of very hard well-water, contaminated from passage of the water through the subsoil, was given up, and the *SEVERN* water substituted, the old water-wheel purchased, and the present works constructed in 1827. In 1870 the conduit reservoir was erected, and the disease is still further ameliorated.

From these investigations of Dr. Thursfield, it would appear that, though the well-water was very hard, varying from 30° to 40°, and even reaching 70°, its bad effects would probably have not been experienced had there been no organic pollution.

Dyspepsia.—Dr. Sutherland is quoted by Mr. Simon, in his Second Report to the City of London, as stating the bad effects experienced by the use of the hard Liverpool New Red Sandstone wells. These were probably the wells at Bevington Bush, and elsewhere, that have been long disused, from their being not only excessively hard, but fearfully polluted. The water supplied by the existing Corporation wells is perfectly pure and palatable.

Dr. Parkes states that the use of waters containing large quantities of calcium sulphate or chloride and magnesian salts produces various dyspeptic symptoms, and considers 10° of permanent hardness, and even less, will affect some people; while waters containing 50 grains per gallon, as in the case of a well at Chatham, no one will drink. He refers to the dislike of grooms to give their horses hard water, which makes their coats "rough and staring."

Phthisis.—The Tables given by the Rivers Pollution Commission show an improvement in the death-rate per 1000, due to the execution of sanitary works, of 4⅓ at Merthyr, of 6 at Cardiff, of 16 at Macclesfield, of 12 at Newport. Examining the returns for the 24 towns, the higher death-rate from phthisis before the improvements was, at Leicester 43⅓, re-

duced 14 per 10,000; Macclesfield 51½, reduced 16; Warwick 40, reduced 7⅓; Salisbury, 44⅔, reduced no less than 22. The phthisis and other pulmonary diseases have carried off before the improvements 53½ per 10,000 persons over 20 years of age, which was reduced to 38½, or a gain of 15 lives per 10,000.

Dr. Buchanan, from his investigation of these towns, having ascertained the fact that the decrease of consumptive death-rate is coincident with the lowering of the surface-waters by improved drainage, made a more detailed examination of the causes leading to consumption in the South-east of England, in which work he was aided by Mr. Whitaker, of the Geological Survey, with the result, that consumptive death-rate is least on pervious soils, and decreases with height above sea-level; that it is less on sloping impervious soils than on flat districts; wetness of soil being the cause of the disease.

An exception to these conditions was noticed in the population living on the low-lying impervious flats on the margin of the coast, which appear to be positively beneficial to consumptive patients, the Isle of Sheppy being a very striking case of this, having the smallest consumptive death-rate of the 58 districts into which the South-east of England is divided. Dover, where a large proportion of the population pass their lives on shingle, is another example of similar conditions; pervious soils, saturated with sea-water, having no ill effects in cases of consumption.

In many tracts of impermeable clays much good might be cheaply done by sinking "dumb wells," to carry off the surface-waters into underlying porous beds.

Malarious Fevers.—The influence of salt marsh-water in producing these fevers and ague has long been noticed in foreign lands, and in our own country in the Bedfordshire and Cambridgeshire Fens, at Tilbury Fort, near Gravesend, and at Sheerness; the well at the latter being highly charged with vegetable *débris*. At Houghton, in Bedfordshire, one

family alone escaped from ague, taking their water supply from a well, instead of from the neighbouring ditches.

The investigations of Professors Pettenkofer and Buhl, of Munich, have long shown a connection between the existence of typhoid fever and a porous soil with a watery subsoil; but, as pointed out by the Rivers Pollution Commission, typhoid epidemics have occurred without this being the case; though there appears to be reason to believe that, if the area of absorption of drinking water answers to these conditions, the polluted matter may be then taken up, and when the water flows underground, chiefly through cracks and fissures, as is the case in the chalk, the strata do not exercise any beneficial oxidizing effect. This is believed to be the cause of the periodic outbreaks of fever in the parish of Croydon; Mr. Baldwin Latham, M. Inst. C.E., having clearly connected the years of excessive death-rate from this cause with an absorption of polluted matter by the intermittent appearance of the springs called the *Bourne*, which, being re-absorbed by the chalk lower down, carry the objectionable elements to the wells in the centre of the old town, which are alone affected. When, through long-continued rains, the lower part of the chalk is charged with water, and the Croydon springs run strongly, they prevent the back-flow of any impure water from the surface. Thus, in the wet years 1859 and 1860, though the *Bourne* in the Caterham Valley had an average discharge of 1500 gallons a minute, it failed to reach the town of Croydon, disappearing in the neighbourhood of Caterham Junction railway station. These were healthy years, because, after artificially abstracting a portion of the lower underground water by pumping, a balance was left overflowing in strong springs at the rate of 3500 gallons a minute.*

When the *Bourne* commences to run after a sudden and copious rainfall, when the springs are comparatively low,

* 'Min. Proc. Inst. C.E.,' vol. xlv. 1876. Disc. on Rainfall, Evaporation, and Percolation.

(as was the case in 1853 and 1866), the water-line under the town is elevated, and an outbreak of enteric fever results.

In an interesting communication made by Mr. Baldwin Latham to the British Association, at York, he states* that it was alleged, by some of the long-established millers on the chalk streams, that they were able to foretell the appearance of rainfall from a sensible increase in the volume of water flowing down the stream before the period of rainfall. He had undertaken a series of observations to investigate the phenomena, and found, in setting up gauges in the *Bourne* flow in the Caterham Valley in the spring of this year (1881), and selecting periods when there was no rain to vitiate the results, that, whenever there was a rapid fall in the barometer, there was a corresponding increase in the volume of water flowing, and, with a rise of the barometer, there was a diminution in the flow. The gaugings of deep wells also confirmed these observations; for where there was a large amount of water in the strata above the water-line, held by capillarity at the period of the year when the wells became sensitive and the flow from the strata was sluggish, a fall in the barometer coincided with a rise in the water-line, and under conditions of high barometric pressure the water-line was lowered. Percolating gauges also gave similar evidence, for after percolation had ceased, and the filter was apparently dry, a rapid fall of the barometer occurring, a small quantity of water passed from the percolating gauges. The conclusion arrived at was, that atmospheric pressure exercises a marked influence upon the escape of water from springs.

The researches of Professor Cohn show that, in the fever-field of Breslau, the well-waters are never free from the fungus he calls *Crenothrix polyspora*. Dr. Klein, after numerous post-mortem examinations of enteric-fever cases, believes the cause of such fevers to be a vegetable germ, probably identical with that found by Prof. Cohn; and Mr.

* 'Nature,' September, 1881.

Baldwin Latham suggests that the porous, damp-soil covering of gravel-covered, fissured chalk affords all the requirements for such low fungoid growths. Be this as it may, the conditions under which pollution is likely to occur are perfectly evident, and no public water supply should be tolerated until means have been taken to exclude all sources of danger; or, in the words of Mr. Simon: "It ought to be made an absolute condition for a public water supply that it should be uncontaminable by drainage."

APPENDIX.

URBAN SANITARY AUTHORITIES OMITTED IN PRECEDING PAGES.

Abersychan (Monm.).—*Acres*, 10,000; population, 13,494; constant supply from *Pontypool Waterworks Co.*; rateable value, 36,132*l.*; under Pontypool Gas and Water Co.'s Act, 36 Vict., Session 1873. [Page 396.]

Abingdon (Berks).—*Acres*, 345; population, 5662; rateable value, 15,960*l.*; supply projected, at present from draw-wells. [Page 232.]

Abram (Lanc.).—Population, 2638. [Plank Lane Brook, page 471.]

Altofts (Yorks).—*Acres*, 1837; population, 3172; rateable value, 32,000*l.*; scheme projected from *Wakefield Corporation Water Supply.* [Page 87.]

Amble (Northb.).—Population, 1888. [Page 51.]

Arnold (Notts).—*Acres*, 4670; population, 5745; rateable value, 13,884*l.* 6*s.*; constant supply from *Nottingham Waterworks Co.* [Page 105.]

Audley (Staff.).—*Acres*, 8450; population, 11,205; rateable value, about 40,000; supply from public and private draw-wells only. [Page 116.]

Austonley (Yorks).—*Acres*, 3223; population, 1662; rateable value, 5552*l.* 18*s.*; supply from public and private wells only.

Balsall Heath (Worc.).—*Acres*, 450; population, 22,497; rateable value, 60,000*l.*; constant supply from *Birmingham Corporation Waterworks.* [Page 121.]

Barton, Eccles, Winton, and Monton (Lanc.).—Population, 21,785; rateable value, 82,000*l.*; supplied by *Manchester Corporation Waterworks.* [Page 470.]

Belgrave (Leic.).—*Acres*, 13,081; population, 7260; rateable value, 21,187*l.* 17*s.* 7*d.*; constant supply of 8000 gallons from the *Leicester Waterworks Co.*; rest from private wells. [Page 127.]

Bexley (Kent).—Population, 8793. [Page 255.]

Bollington (Chesh.).—*Acres*, 450; population, 3962; rateable value, 9186*l.*; supply from wells and springs only. [Page 445.]

Brampton and Walton (Derby).—*Acres*, 10,098; population, 7657; rateable value, 26,328*l.* 6*s.*; supply constant from the *Chesterfield Waterworks Co.*, under their Act. [Page 94.]

Bredbury (Chesh.).—Population, 5552; rateable value, 20,751*l.*; constant supply of 18,000 gallons from the Woodhead reservoir of the *Manchester Corporation Waterworks*, taken at Haughton; 1,000,000 gallons will be supplied, if necessary, under Public Health Act, 1875. [Page 447.]

Brierfield (Lanc.).—*Acres*, 1018; population, 4088; rateable value, 6849*l.* 15*s.*; constant supply of 10 gallons per head from *Nelson Local Board's Waterworks*, under their Act. [Page 515.]

Broadstairs (Kent).—Population, 4362; supply constant, from two chalk wells. [Page 264.]

Bromborough (Chesh.).—*Acres*, 1555; population, 1381; rateable value, 11,138*l.*; constant supply used averages 6904 gallons per day, from *Wirral Waterworks Co.*, under their Act, 11 & 12 Vict. c. 63, s. 75. [Page 436.]

Brotton (Yorks).—Population, 4185. [Basin XXIII., page 63.]

Burgess Hill (Sussex).—Population, 3968. [Adur Basin, page 282.]

Cartworth (Yorks).—*Acres*, 1886; population, 2055; rateable value, 453*l.* Hollowgate, 6422*l.* Cartworth; constant supply of 600 gallons, from a small spring, stored in a small reservoir; under Local Government Act, 1858.

Chesterton (Camb.).—Population, 5705. [Page 154.]

Chipping Norton (Oxon).—Population, 4167; rateable value, 9556*l.* 15*s.* 8*d.*; constant supply pumped from underground reservoir, storing spring at the Glyme; under Public Health Act, 1875. [Page 226.]

Chorley (Chesh.).—Population, 2085; no public supply.

Church (Lanc.).—Population, 4850. [Calder, Ribble Basin, page 511.]

Claines (Worc.).—Population, 3814. [Page 369.]

Crowle (Linc. and Yorks).—*Acres*, 7146; population, 3439; rateable value, 16,710*l.*; supply from public and private wells. [Trent, page 131.]

Crumpsall (Lanc.).—Population, 8151; rateable value, 24,215*l.*; supply from *Manchester Corporation Waterworks*. [Page 460.]

Cumberworth and Cumberworth Half (Yorks).—Population, 1471; rateable value, 3715*l.* 19*s.*; supply from wells and streams; the Board is trying to arrange for supply from *Dewsbury and Heckmondwike Waterworks*. [Page 86.]

Dawley (Salop).—*Acres*, 2625; population, 9200; rateable value, 17,991*l.*; supply from springs only. [Page 383.]

Denton (Lanc.).—*Acres*, 1630; population, 7660; rateable value, 25,000*l.*; constant supply from *Manchester Corporation Waterworks*. [Page 454.]

Dorking (Surrey).—Population, 6328. [River Mole, page 240.]

Dwygyfylchi (Carn.).—*Acres*, 3840; population, 2131; rateable value, 1576*l.*; supply constant from reservoir storing brooks from mountain springs; under 11 & 12 Vict. c. 63.

East Ham (Essex).—Population, 9815. [River Roding, page 172.]

Egremont (Cumb.).—Population, 5976. [River Ehen, page 551.]

Fulstone (Yorks).—*Acres*, 1949; population, 1909; rateable value, 5819*l.*; supply from public and private wells only, unfiltered; scheme suggested.

Golcar (Yorks).—Population, 7655; rateable value, 22,000*l.*; supply arranging from the *Huddersfield Corporation Waterworks*. [River Colne, page 88.]

Grange (Lanc.).—Population, 1150; rateable value, 12,100*l.*; supply from springs on Silurian rocks, stored in reservoir at Newton-in-Cartmel, one mile distant; 25,000 gallons used, 50,000 available; under provisional orders of the Local Government Board. [Page 539.]

Grasmere (West.).—*Acres*, 1050; population, 684; rateable value, 5590*l.*; constant supply from Tongue Ghyll; under Public Health Act, 1875. [Page 541.]

Harborne (Staff.).—*Acres*, 1411; population, 6433; rateable value, 20,500*l.*; supply from *Birmingham Corporation Waterworks*. [Page 121.]

Haughton (Lanc.).—*Acres*, 887; population, 5051; rateable value, 15,474*l.* 15*s.*; supply from *Manchester Corporation Waterworks*. [Page 453.]

Haverfordwest (Pemb.).—Population, 6393; rateable value, 17,185*l.* 13*s.* 8*d.*; supply constant of 14,000 gallons from reservoir supplied from springs; under Public Health Act. [Page 405-6.]

Hayward's Heath (Sussex).—Population, 1814. [Sussex Ouse, page 280.]

Heaton Norris (Lanc.).—*Acres*, 1564; population, 5490; rateable value, 28,910*l.*; supply from *Stockport District Waterworks Co.* [Page 454.]

Hebburn (Durh.).—*Acres*, 1178; population, 12,241; rateable value, 46,664*l.* 10*s.*; constant supply from *Sunderland and South Shields Waterworks Co.* [Page 57.]

Hepworth (Yorks).—*Acres*, 2177; population, 1047; rateable value, 4097*l.*; supply from springs. [Page 88.]

Higher Bebington (Chesh.).—Population, 1197; rateable value, 4000*l.*; supply from the *Wirral Waterworks Co.* [Page 436.]

Holme Cultram (Cumb.).—*Acres*, 24,828; population, 4220; rateable value, 30,472*l.*; supply from private draw-wells.

Holyhead (Ang.).—*Acres*, 774; population, 8543; rateable value, 14,408*l.* 11*s.* 7*d.*; constant supply of 70,000 gallons from reservoir storing springs; under Holyhead Waterworks Act, 1866. [Page 417.]

Horwich (Lanc.).—*Acres*, 3254; population, 3761; rateable value, 14,313*l.*; supply from wells and streams only. [Page 501.]

Lees (Lanc.).—*Acres*, 202; population, 3511; rateable value, 11,200*l.*; constant supply from *Oldham Corporation Waterworks*. [Page 458.]

Lepton (Yorks).—Population, 3019; rateable value, 6409*l.*; supply from *Huddersfield Corporation Waterworks*, and artesian wells. [Page 88.]

Levenshulme (Lanc.).—Population, 3557; rateable value, 17,279*l.* 17*s.* 6*d.*; supply from *Manchester Corporation Waterworks*. [Page 457.]

Little Crosby (Lanc.).—*Acres*, 1750; population, 583; rateable value, 4912*l.*; supply from draw-wells. [Page 492.]

Lower Bebington (Chesh.).—*Acres*, 1542; population, 3898; rateable value, 19,097*l.*; supply from *Wirral Waterworks Co.* [Page 436.]

Macclesfield (Chesh.).—*Acres*, 3004; population, 37,514; rateable value, 85,586*l.*; constant supply of 663,000 gallons from reservoir, storing streams from hill district, five miles to south-east; under Macclesfield Borough Waterworks Act, 1849. (River Bollin, page 445.]

Millom (Cumb.).—*Acres*, 1313; population, 6231; rateable value, 46,667*l.* 7*s.* 1*d.*; supply constant from reservoir storing Whicham Beck; under Millom Gas and Water Act, 1875. [Page 548.]

Much Wenlock (Salop).—*Acres*, 8821; population, 2321; rateable value, 16,043*l.*; supply from wells and springs only. [Page 383.]

New Mills (Derby).—*Acres*, 4834; population, 6552; rateable value, 20,146*l.*; supply from three private reservoirs. [River Goyt, page 448.]

Newquay (Cardigan).—*Acres*, 640; population, 1328; rateable value, 1140*l.*; supply chiefly rain-water. [Basin CII., page 409.)

Newton Heath (Lanc.).—*Acres*, 1350; population, 29,188; rateable value, 80,846*l.*; supply from *Manchester Corporation Waterworks.* [Page 453.]

Quarry Bank (Staff.).—*Acres*, 985; population, 6238; rateable value, 7821*l.* 8*s.* 6*d.*; supply from artesian wells. [Page 370.]

Quickmere (Yorks).—Population, 3660; rateable value, 9400*l.*; constant supply from *Oldham Waterworks.* [Page 88.]

Rainford (Lanc.).—*Acres*, 5872; population, 3745; rateable value, 20,933*l.* 3*s.*; local wells and pumps only. [Page 478.]

Ramsbottom (Lanc.).—Population, 5242; rateable value, 21,715*l.*; constant supply from *Bury Corporation Waterworks.* [Page 464.]

Ryton-on-Tyne (Durh.).—*Acres*, 5149; population, 4568; rateable value, 26,708*l.*; no public water supply. [Page 56.]

Sale (Chesh.).—*Acres*, 1981; population, 7916; rateable value, 47,878*l.* 3*s.*; supply from *North Cheshire Water Co.*, who obtain their supply from Manchester Corporation. [Page 446.]

South Darley (Derby).—*Acres*, 1963; population, 579; rateable value, 3430*l.*; supply from wells and springs only. [Page 109.]

Stapleton (Glouc.).—Population, 7811.

Stayley (Chesh.).—*Acres*, 2136; population, 2671; rateable value, 11,000*l.*; constant supply from reservoirs storing springs.

Swadlincote (Derby).—*Acres*, 684; population, 2982; rateable value, 6600*l.*; supply from pumps and wells only. [Page 112.]

Swinton (Yorks, W.R.).—Population, 7611.

Trawden (Lanc.).—*Acres*, 6807; population, 2164; rateable value, 6200*l.*; supply projected by private company, from a reservoir. [Page 514.]

Upper Mill (Yorks).—Population, 1384; rateable value, 2900*l.*; no public supply, but the district is included in the Ashton-under-Lyne,

Stalybridge, and Dukinfield Waterworks Act, 1870 (38 & 39 Vict. Amendment Act, 1875); works at Greenfield nearly completed. [Page 88.]

West Derby (Lanc.).—*Acres*, 5561; population, 6118; rateable value, 168,871*l.*; supply chiefly from *Liverpool Corporation Waterworks*, partly from wells. [Page 492.]

Whickham (Durham).—*Acres*, 5302; population, 7975; rateable value, 31,860*l.*; supply partly from *Consett Water Company*, and partly from *Newcastle and Gateshead Water Company*. [Page 53.]

Whitworth (Lanc.).—Population, 11,101; rateable value, 37,555*l.*; constant supply of 20 gallons per head from *Rochdale Corporation Waterworks*. [Page 463.]

Wuerdle and Wardle (Lanc.).—Population, 4631; rateable value, 18,547*l.*; supply from *Rochdale Corporation Waterworks*. [Page 463.]

Ynyscynhaiarn (Carn.).—*Acres*, 5346; population, 5488; rateable value, 9786*l.*; a company give a partially constant supply from Tecwyn Lake, the water is stored in a service reservoir; under Gas and Waterworks Facilities Act, 1870.

RIVER BASIN OMITTED.

O.S. CATCHMENT BASIN CXXV.

Area, 55 square miles, consisting of 14 square miles of Old Red Sandstone, 25 of Carboniferous Limestone, 4 of Triassic rocks, and 12 of Lias. Chief places, Portskewett, Magor, Newchurch, St. Bride's, Undy. [Page 395.]

County Population Omitted [Page 553].

County.	Population in 1871.	Density.	Proportion in this Group.	Probable Population.
Denbighshire	104,266	3·6	$\frac{1}{3}$	34,756
„ in 1881 ..	108,931	3·1	$\frac{1}{3}$	36,310

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